# HYDROGEOLOGY OF THE MUIR BEACH COMMUNITY SERVICES DISTRICT WELL SITE, FRANK VALLEY, REDWOOD CREEK, CALIFORNIA

## GOLDEN GATE NATIONAL RECREATION AREA

## PRELIMINARY REPORT

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# Introduction

Muir Beach is a small community located on the coastal headlands at the mouth of Redwood Creek in southern Marin County. The Muir Beach Community Services District (MBCSD) owns and operates a water distribution system that provides potable water to the community. The water supply source is a shallow well along Redwood Creek on MBCSD property in Frank Valley, approximately 1 mile upstream from the ocean (figure 1). The MBCSD property is 0.60 acres, including land on both sides of Redwood Creek. The property is surrounded by California State Park and National Park Service lands.

The primary purpose of this report is to present the results of aquifer testing conducted at the MBCSD Well Site in July 1999 and to discuss hydrologic impacts from pumping groundwater at the MBCSD Well Site.

## Geographic & Geologic Setting

Redwood Creek is a coastal stream in Marin County, approximately 4 miles long, draining an area of 7½ square miles. The creek originates from springs on Mt Tamalpais and flows generally south, discharging to the Pacific Ocean through an intermittent tidal lagoon at Muir Beach. The upper part of the creek flows through Redwood Canyon in Muir Woods National Monument. The canyon is steep-sided with a narrow valley floor. Below Muir Woods, the creek flows through Frank Valley for approximately 2 miles before reaching the ocean. Frank Valley has a fairly flat valley floor, ranging from about 200 feet wide at the head of the valley to about 500 feet wide at the lower end of the valley. A schematic geologic cross section through the MBCSD Well Site is shown in figure 2. Vegetation in the drainage basin is composed of mixed conifer forests in the upper valleys, mixed hardwoods, chaparral, and grasslands on the slopes, and a corridor of riparian vegetation (willows and alders) along Redwood Creek.

Bedrock in the area is comprised of rocks of the Franciscan Group, a series of sedimentary, metamorphic, and igneous rocks of Late Jurrasic and Cretaceous age (Jennings, 1977). Redwood Creek has downcut through these rocks forming Redwood Canyon and Frank Valley. Frank Valley has subsequently been partially filled with unconsolidated alluvial deposits. Alluvial fill is common in California coastal valleys and can be several hundred feet thick. These alluvial fills occurred following the rise in sea level at the end of the last glacial age that consequently raised the base level of coastal streams. In response, the streams ceased downcutting and deposited alluvium, building up the valley floors to present elevations. Thickness of alluvium at the MBCSD Well Site is not known. Driller's reports from construction of the water supply wells indicate the alluvium is at least 37 feet thick. Laudon (1988) hypothesized that the thickness may be 90 feet, based on projection of the slopes of the valley walls into the subsurface.

The alluvium is unconsolidated and heterogeneous. Sediment exposed in the stream bank and streambed is a mixture of silt, fine to coarse-grained sand, and pebble–sized gravel. Driller's logs for wells at the site indicate a variety of sediments were encountered, from clay to gravel. Five deep (35-37 feet) wells have been drilled at the site. The driller's logs for these wells are similar; showing a surficial layer of 1-2 feet of topsoil, 6-8 feet of clay mixed with gravel or sand, 2-3 feet of gravel, approximately 20 feet of clay and gravel, and 5 feet of gravel or boulders. The stratigraphy is represented graphically in figure 3, the sketch of the well constructed by MBCSD in 1996. While there is some similarity in the stratigraphy at all of the wells, there is enough variability to indicate that the alluvial aquifer should not be described as a multi-layered system of aquifers and aquicludes. The alluvium is a heterogeneous mix of clay, sand, and gravel, typical of material weathered from Franciscan Formation bedrock and reworked by the flowing water of Redwood Creek.

A sketch of the driller's log for the MBCSD Supply Well (constructed in 1996) at the MBCSD Well Site is shown in figure 3. Driller's logs for the 4 deep wells constructed by MBCSD are summarized in table 1. The driller's logs indicate what appears to be a layered aquifer system and suggests that we would expect the deeper aquifer to represent

a basal aquifer overlying bedrock. It further suggests that overlying clay layers might confine the basal aquifer and thus limit hydraulic interconnection with the stream.

Data obtained from hydrologic monitoring at the site contradicts the hypothesis of a confined basal aquifer. Monitoring has shown that the water table throughout the area responds to pumping from the MBCSD Supply Well. Monitor wells both close to and distant from the pumped well respond to pumping. Shallow and deep wells respond to pumping. Even shallow wells located within a few feet of the creek show the effects of pumping from the MBCSD Supply Well. Data showing the interconnection of all hypothesized aquifers and aquicludes at all distances from the creek and well will be presented later in this report.

## Site Description

The MBCSD Well Site is approximately 0.60 acres located in Frank Valley, approximately ½ mile upstream from the Shoreline Highway (Hwy 1) bridge. The site includes land on both sides of Redwood Creek and is surrounded by National Park Service and California State Park lands. In addition to being the location of water supply wells, the residents of Muir Beach use the area as a community park.

MBCSD has two deep wells at the site. Only the new well is being used, it will be referred to as the "MBCSD Supply Well" in this report. Production rates in the Old Well had declined, forcing the need to construct a new well. The Old Well is maintained for monitoring purposes and as an emergency backup well. MBCSD had drilled another well in 1982, but it was immediately filled and abandoned due to low yield. An older well at the site, drilled in 1970, has been filled and abandoned. MBCSD constructed 16 shallow monitor wells in an "X" pattern around the new supply well. These monitor wells are 8-9 feet deep and located 5, 10, 15, and 20 feet from the supply well. They were constructed to monitor the response of the "upper aquifer" to pumping from the "lower aquifer"

The National Park Service installed 5 shallow piezometers along the bank of Redwood Creek at the site. These piezometers were constructed by driving 2-foot long drive points

(with attached pipe) to various depths, generally 2-4 feet below ground surface. NPS also constructed a deep (35 feet) monitor well near the creek prior to the July 1999 aquifer testing.

There is one other monitor well at the site; a deep (30 feet) abandoned well located on California State Park land. The well is about 60 feet northwest of the MBCSD Supply Well.

Locations of all monitor wells are shown on figure 4. Table 2 summarizes the depth and perforated interval for piezometers and monitor wells at the site.

The site is a fairly flat area on the floodplain of Redwood Creek. The channel of Redwood Creek is about 25 feet wide and downcut about 6-8 feet below the valley floor. In addition to supply and monitor wells, the site contains several buildings for water treatment and general maintenance by MBCSD, a volleyball court, and various booths and facilities used by the community of Muir Beach for picnics and social gatherings.

## July 1999 Aquifer Test

An aquifer test was conducted at the MBCSD Well Site in July 1999. The MBCSD Supply Well was used as the pumping well. Water levels in all deep wells and piezometers were monitored throughout the test period. Streamflow in Redwood Creek was monitored upstream and downstream from the MBCSD Well Site. The MBCSD Supply Well had been pumping continuously for several days over the Fourth of July weekend to fill the MBCSD storage tanks. The pump was shut off on the evening of July 7. Water table recovery was monitored for 36 hours. The well was then pumped for 48 hours, followed by an 8-hour recovery period. Average pumping rate during the test was 33 gallons per minute (gpm). Pumping and recovery periods are shown on figure 5.

Deep Wells

Water levels were monitored in 3 deep wells during the test; the old MBCSD well (Old Well), an abandoned well on California State Park property (State Park Well), and a new monitor well near the creek (New Monitor Well). The old MBCSD well is the former supply well. The yield of the well had decreased and MBCSD constructed a new well. The Old Well is maintained as an emergency backup well and for monitoring purposes. We have no information about the well on California State Park property; other than the total depth is 32 feet. Presumably, it is completed in the "lower aquifer" with construction similar to the other deep wells. NPS constructed a new deep monitor well just prior to the aquifer test. The well is located a few feet from the creek, about 20 feet downstream from the footbridge. This location is quite close to that of a former MBCSD Supply Well that was constructed in 1970 and abandoned and filled in 1996. Locations of deep wells at the MBCSD Well Site are shown on figure 4.

In a homogeneous, isotropic aquifer, one that is not affected by recharge from a nearby stream or bounded by a relatively impermeable bedrock barrier, we would expect that water table drawdown would decrease as the distance from the pumped well increased. We would also expect that two observation wells, located similar distances from the pumped well, would have approximately the same amount of drawdown. This is not what we observed at the MBCSD Well Site.

The Old Well is 10 feet from the pumped well. Water level in the Old Well is drawn down about 1½ feet when the Supply Well is pumped (figure 6). The State Park Well is 60 feet from the pumped well. Water level in the State Park Well is drawn down about 3 feet when the Supply Well is pumped (figure 7). The New Monitor Well is 65 feet from the pumped well. Water level in the New Monitor Well is drawn down about ¾ foot when the Supply Well is pumped (figure 8).

We would expect to see the greatest amount of drawdown in the Old Well and very close to the same amount of drawdown in both the State Park Well and the New Monitor Well.

These relationships may not occur if the water table response is affected by recharge from the stream or the presence of an impermeable bedrock boundary (valley wall). The greatest amount of drawdown was observed in the State Park Well. This may be due to the nearby presence of impermeable bedrock bounding the alluvial aquifer as a subsurface expression of the valley wall, or that the pumped well intercepts recharge from the creek before it reaches the State Park Well. Drawdown at the Old Well was only half as much as at the State Park Well, even though the Old Well is much closer to the pumped well. Recharge from the creek may be maintaining a higher water table between the creek and the pumped well. We would have expected drawdown in the New Monitor Well to be similar to that at the State Park Well, as they are approximately the same distance from the pumped well. We observed much less drawdown at the New Monitor Well, but can not say for certain whether that is a result of stream recharge maintaining a higher water table at the New Monitor Well, the effect of an impermeable boundary near the State Park Well, or some combination of effects. When considered together, the data from the deep wells indicate that as the drawdown cone expands around the pumped well, it encounters the effects of both recharge from the creek on one side and increased drawdown from the effects of an impermeable boundary (valley wall) on the other side.

On some of the hydrographs (figures 6 to 8) there is a noticeable lowering of the water table about mid-day. This may be attributable to "pumping" of groundwater by riparian vegetation during the warm sunny part of the day when evapotranspiration is greatest. We did not observe this effect at all wells, or on all days. It is most noticeable at mid-day on July 10 at the State Park Well and at mid-day on July 8, 10, and 11at the Old Well.

Figure 9 shows a hydrograph of water levels at the 3 deep monitor wells. The hydrograph shows that during non-pumping periods water levels at the Old Well and New Monitor Well are approximately the same and the water level at the State Park Well is much higher. Water level in the creek was slightly lower than the water table elevation at the Old Well or the New Monitor Well. Under these conditions, groundwater flow is toward the creek.

During pumping periods, groundwater flow directions are reversed, with groundwater from the vicinity of the creek flowing toward the pumping well. Also, the water level at the State Park Well is much lower than at the Old Well located 10 feet from the pumping well, possibly showing the effect of an impermeable bedrock valley.

Figure 10 shows a cross section through the site with static and pumping water levels measured in the deep wells. This figure shows that when the MBCSD Supply Well is not being pumped, groundwater flow is toward the creek. When the well is pumped, groundwater flow is from the creek toward the well.

The water level in Redwood Creek adjacent to the New Monitor Well remained at 16.5 feet MSL throughout the test period, fluctuating only about 0.01'. Static water level at the New Monitor Well was 16.79 feet MSL. During pumping, the water level was 15.99 feet MSL. These data clearly show that groundwater flow is toward the creek when the well is not being pumped and that infiltration from the creek is induced when the well is pumped.

Water level data from the deep wells were analyzed by the Hantush-Jacob method for leaky confined aquifers as described in Lohman (1972). Data were plotted on logarithmic paper and matched to the type curves on Plate 3 (Lohman, 1972) as shown on figures 11 to 13. These figures show both the matches to the Hantush-Jacob type curves and the departure from the Theis curve. At all three wells, data departs from the Theis type curves about 100-200 minutes after pumping was started. Measured drawdown after this time was less than would have been expected for a hydrologic system where all of the water was derived from storage in the aquifer. This indicates that there was an additional source of water, other than just aquifer storage, providing water to the well. That additional source of water is almost certainly recharge from Redwood Creek.

Data plots for the State Park Well and the Old Well both show a short period when drawdown was greater than expected (data points above the type curve). This occurs about 7 to 40 minutes after pumping started at the Old Well and about 25 to 200 minutes

after pumping started at the State Park Well. These phenomena may be an effect of an impermeable boundary, such as the buried bedrock forming the boundary of the alluvial aquifer. The time difference for observing this increased drawdown at the two wells may be partly explained by their distance from the creek (the assumed recharge source). The Old Well is closer to the creek and would exhibit the effects of recharge sooner than the more distant State Park Well. . An alternative explanation is that the additional drawdown is due to increased evapotranspiration of trees and riparian vegetation at the site, which can resemble the effects of groundwater pumping. Similar increases in drawdown are seen on the data plots about 1500-1700 minutes into the test, corresponding with increased evapotranspiration at mid-day on the second day of the pumping period.

Calculated transmissivity values show the heterogeneity of the aquifer system. Transmissivity at the State Park Well is about 400 $ft^2$/day. This may represent fine-grained sediments at the edge of the valley. Transmissivity at the Old Well is 1700 $ft^2$/day and at the New Monitor Well is 1300 $ft^2$/day. These higher values probably represent coarse-grained sediments found near the middle of the valley. Sediments deposited in the valley by a flowing stream formed the alluvial aquifer. Fine-grained sediments would tend to be deposited along the valley margins, usually as floodplain deposits. In the middle of the valley, sediments would tend to be reworked by the meandering of the stream and the fine-grained fraction would be washed downstream, leaving mostly coarse-grained sediments. These sedimentary depositional processes would result in lower transmissivity at wells located toward the margins of the valley and higher transmissivity at wells located near the middle of the valley.

Calculated storage coefficients ($2.6 \times 10^{-2}$, $8.5 \times 10^{-2}$, $1.8 \times 10^{-3}$ ) are characteristic of semi-confined or leaky confined aquifer systems. Unconfined aquifers generally have a storage coefficient of about 0.1-0.3 and confined aquifers generally have a storage coefficient of about $10^{-5}$ to $10^{-3}$ (Heath, 1983).

Hypothesized hydrogeologic conditions at the site, including the effects of a recharge boundary (Redwood Creek) and an impermeable boundary (bedrock), are shown graphically in figure 14.

Shallow Piezometers

Water levels were monitored in 4 shallow piezometers (P-2, P-9, P-6, and P-10) located along the creek bank during the aquifer test (figure 4). These piezometers were constructed by driving sand points to a few feet below ground surface. Construction depths and perforated intervals for these piezometers are provided in Table 2. The shallow piezometers provide a measure of drawdown in the "upper aquifer" and allow us to make some inferences about the vertical hydraulic conductivity of the aquifer and interconnectivity of the "lower" and "upper" zones in the aquifer.

Piezometer P-2 is located 40 feet upstream from the footbridge, on the right bank of the creek, and is screened from 14.9-16.9 feet MSL. Water level in the creek adjacent to the piezometer was 16.9 feet MSL during the aquifer test. Water level in piezometer P-2 rose to 16.8 feet during the recovery period and was drawn down to 16.67 feet during the pumping period, a drawdown of 0.13 feet. Drawdown was observed in piezometer P-2 beginning with the first measurement, 1 minute after the pump was turned on. The water level did not change significantly after 4 hours into the test, probably due to establishment of new equilibrium conditions between the creek, piezometer P-2, and the pumped well. Measured water levels at Piezometer P-2 during the aquifer test are shown on figure 15.

Piezometer P-9 is located on the upstream side of the footbridge, on the right bank of the creek, and is screened from 14.6-16.6 feet MSL. Water level in the creek adjacent to the piezometer was 16.53 feet MSL during the aquifer test. Water level in piezometer P-9 rose to 16.6 feet during the recovery period and was drawn down to 16.48 feet during the pumping period, a drawdown of 0.12 feet. Drawdown was observed in piezometer P-9 beginning with the first measurement, 2 minutes after the pump was turned on. The water level did not change significantly after 4 hours into the test, probably due to

establishment of new equilibrium conditions between the creek, piezometer P-9, and the pumped well. Measured water levels at piezometer P-9 during the aquifer test are shown on figure 16.

Piezometer P-6 is located 30 feet downstream of the footbridge, in the creek, but very near the right bank of the creek, and is screened from 11.4-13.4 feet MSL. Water level in the creek adjacent to the piezometer was 16.5 feet MSL during the aquifer test. Water level in piezometer P-6 rose to 16.5 feet during the recovery period and was drawn down to 16.4 feet during the pumping period, a drawdown of 0.1 feet. Drawdown was observed in piezometer P-6 beginning with the first measurement, 4 minutes after the pump was turned on. The water level did not change significantly after 2 hours into the test, probably due to establishment of new equilibrium conditions between the creek, piezometer P-6, and the pumped well. Measured water levels at piezometer P-6 during the aquifer test are shown on figure 17.

Piezometer P-10 is located 30 feet downstream of the footbridge, on the right bank of the creek, and is screened from 13.8-15.8 feet MSL. Water level in the creek adjacent to the piezometer was 16.5 feet MSL during the aquifer test. Water level in piezometer P-6 rose to 16.6 feet during the recovery period, probably in response to water level recovery in the aquifer and raising of the water level in the creek from impounding water behind the weir. The water level in piezometer P-10 did not change significantly in response to pumping or recovery periods of the aquifer test. The water level fluctuated within a few hundredths of a foot of 16.60 feet MSL. The lack of change may have been caused by impoundment of water in the creek at a level adjacent to the perforated interval of the piezometer located 1 foot from the creek, essentially creating a constant head condition. Changes of 0.01-0.02 foot may be attributed to measurement error, or slight differences in technique of the individuals making the measurements. Measured water levels at piezometer P-6 during the aquifer test are shown on figure 18.

Piezometers P-6 and P-10 are about 4 feet apart from one another. The perforated interval

of P-6 is below the creek bed. The perforated interval of P-10 is at the same level as the water in the creek. Water levels in P-6 responded to pumping, but water levels in P-10 did not.

Shallow Monitor Wells

There are 16 shallow monitor wells constructed by MBCSD in close proximity to the MBCSD Supply Well (figure 4). These monitor wells are in an "X" pattern, at distances of 5, 10, 15, and 20 feet from the MBCSD Supply Well. The monitor wells were installed by auguring down to about 9 feet deep; placing perforated drainpipe in the hole, and backfilling with drill cuttings. The shallow monitor wells provide a measure of drawdown in the "upper aquifer" in the vicinity of the pumped well and allow us to make some inferences about the vertical hydraulic conductivity of the aquifer and interconnectivity of the "lower" and "upper" zones in the aquifer.

During construction of the shallow monitor wells, a 4-inch PVC cap was placed over one end of a length of PVC drainpipe. The end with the cap was placed in a hole that had been augured to below the water table. The PVC cap was intended to prevent soil from entering through the bottom of the monitor well. This cap also effectively creates a reservoir of water in the bottom of the well below the lowermost hole in the sidewall of the drainpipe. What appears to be a stable water level during the drawdown portion of the aquifer test may be repeated measurements of water trapped in the bottom of the monitor well. We don't know for certain that the water table was only drawn down about a foot during pumping, as would be suggested from looking at the data plots. A preponderance of data from the 16 shallow monitor wells strongly suggests that the water table is drawn down about a foot when the MBCSD Supply Well is pumped. Water levels in the shallow monitor wells quickly reach equilibrium, suggesting that there is good hydraulic communication between the "upper" to "lower" aquifers and also that water levels in the "upper" aquifer are maintained by infiltration from Redwood Creek.

Data from shallow monitor wells located 5 feet and 20 feet in each direction from the pumped well are shown in figures 19 to 22. These data are representative of the water

level changes in the "upper" aquifer.

Static water levels in the monitor wells east and west from the pumped well are approximately the same. There is a slight east to west groundwater flow component (downstream) as would be expected. When the well is pumped, the effect of recharge from the creek on water levels in wells 5-E and 20-E is readily apparent. Drawdown in the wells closer to the creek (5-E and 20-E) is much less than in the wells farther from the creek (5-W and 20-W).

A similar pattern is seen in the shallow monitor wells north and south of the pumped well. Water levels in monitor wells south of the pumped well (closer to the creek) show less drawdown than wells north of the pumped well (farther from the creek). Figure 21 shows water levels in the shallow monitor wells south of the pumped well. When the MBCSD Supply Well is not being pumped, groundwater flow is from well 5-S toward 20-S and the creek. When the MBCSD Supply Well is being pumped, groundwater flow is from the creek toward well 20-S and then toward well 5-S. (Water level in the creek is about 16.5 feet MSL.)

Streamflow

Two 90° v-notch weirs were installed in Redwood Creek during the aquifer test period in July 1999. One weir was about 300 feet upstream from the MBCSD Well Site and was fairly effective for monitoring changes in flow during the test period. Water level stage at the upstream v-notch was affected by diurnal fluctuations, ranging from about 0.15 feet above the v-notch to 0.25 feet above the v-notch (figure 23). Streamflow corresponding to these stages ranges from 0.02 to 0.08 cfs (9 to 36 gpm). The diurnal fluctuation, measured at the upstream weir, is about 0.06 cfs (27 gpm). Diurnal fluctuation occurred regardless of whether the well was being pumped. It appears that the amount of diurnal fluctuation is more dependent on local weather (warm, sunny days vs. cool, cloudy days), rather than operation of the MBCSD Supply Well.

In the analysis of data from the upstream weir, it was assumed that the amount of underflow through the streambed and adjacent gravel bar was constant throughout the test period. Groundwater flow through the gravel bar and streambed is proportional to the difference in water level between the pool upstream from the weir and the creek downstream from the weir. More leakage (and bypass around the weir) would occur when the water level in the pool was higher. If we were able to measure all of the water flowing down the creek, there would have been a larger difference in the diurnal fluctuation.

The second weir was installed about 100 feet downstream of the footbridge. At the downstream weir, higher flows during the night overflowed or bypassed the temporary dam constructed to divert water through the v-notch weir. Flow measurements through the downstream weir were essentially constant throughout the test period. The depth of water flowing through the weir was about 0.45 feet, or 0.34 cfs. It was observed that the amount of water flowing over or around the sandbag dam increased at night when evapotranspiration was minimal.

Streamflow was measured by standard gaging techniques at two locations on July 12, following the aquifer test. Streamflow downstream from the footbridge was 0.37 cfs and flow upstream of the upstream weir was 0.39 cfs.

The stage in Redwood Creek was monitored at staff gages attached to piezometers P-6 (bout 30 feet downstream of the foot bridge) and P-8 (on the upstream side of the foot bridge. Water surface elevations at the two sites are shown on figure 24. The rise at the beginning of the hydrograph (July 7-8) is a result of the creek being impounded behind the downstream weir. Otherwise, the hydrographs show no significant changes.

We conclude that streamflow in Redwood Creek in the vicinity of the MBCSD Well Site was 0.35-0.40 cfs during the test period. It is not possible to measure flow more accurately without constructing artificial structures, such as concrete weirs, in the channel. Diurnal fluctuation is on the order of 0.06 cfs (27 gpm). The MBCSD Supply

Well is pumped at a rate of about 33 gpm, or 0.07 cfs. It is unlikely that we would be able to measure the streamflow depletion due to pumping from the well or separate the effects of evapotranspiration from pumping at the well, even under optimal conditions. That doesn't mean that streamflow depletion does not occur, only that we are not able to measure streamflow accurately enough to detect it.

## Discussion

The alluvium in the Redwood Creek valley constitutes a single aquifer. It is heterogeneous and somewhat layered, but groundwater throughout the valley is hydraulically interconnected. Pumping water from the MBCSD Supply Well causes drawdown in wells and piezometers in all directions from the pumped well and at all depths in the aquifer. Drawdown was observed in shallow wells next to the creek and deep wells and shallow wells next to the pumped well. The amount of drawdown observed in various monitor wells is affected by stratigraphy and local hydrogeologic conditions.

Groundwater in the alluvium and surface water in Redwood Creek are part of an integrated hydrologic system. The waters are clearly interconnected. Water can not be taken from any source in the valley without affecting other components of the hydrologic system. Pumping groundwater from the MBCSD Supply Well lowers the water table in the general vicinity of the well. Lowering the water table results in either intercepting groundwater that would otherwise have discharged to the creek or inducing infiltration from the creek to the groundwater system. Either scenario results in less water in the creek.

The current pumping rate (33 gpm or 0.07 cfs) of the MBCSD Supply Well is too small to produce a detectable change in streamflow in Redwood Creek. That does not mean there is no reduction, but that our ability to measure streamflow in natural channels does not have enough precision.

We were able to measure diurnal fluctuation of flow in Redwood Creek caused by evapotranspiration of riparian vegetation. The amount of observed diurnal fluctuation was approximately the same as the current pumping rate of the MBCSD Supply Well. So why couldn't we detect streamflow depletion due to pumping of the well? One reason is that we did not have a good streamflow monitoring site downstream from the MBCSD Well Site. Our attempt to monitor streamflow at the downstream weir was unsuccessful because there was too much leakage around the weir and through or over the sandbag dam. The second reason we did not observe stream depletion in response to pumping is because much of the groundwater being pumped initially comes from storage in the aquifer, which causes a time delay on propagation of impacts to the creek. Water pumped from the well comes from both reduction of storage in the aquifer and infiltration from the creek. Groundwater taken from storage is gradually replaced from inflow of groundwater from the upper part of the valley and from infiltration from the creek. Infiltration occurs over a long reach of the creek. It does not occur as a point source impact.

## Conclusions

1. The alluvium in the Redwood Creek valley constitutes a single aquifer.
2. Surface water in Redwood Creek and groundwater in the alluvial aquifer are hydraulically interconnected.
3. Groundwater pumping at the MBCSD Well Site in Frank Valley reduces streamflow a small amount by inducing infiltration of surface water to the alluvial aquifer.

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# TABLES

Table 1. COMPOSITE TABLE OF FOUR WELL DRILLER'S LOGS

| Approximate Elevation | Well #1, New Primary well drilled 6/20/96 | Well #2, Backup well, Drilled 7/27/82 | Well #3, drilled 10/70, closed & sealed 7/96 | Well #4, low yield, drilled & sealed 7/82 |
|---|---|---|---|---|
| +24.0 | Topsoil | Brown clay w/gravel | Topsoil | Brown clay & sand |
| +23.0 | Topsoil to el. +22.5 | Brown clay w/gravel | Topsoil | Brown clay & sand |
| +22.0 | Brown clay w/rock | Brown clay w/gravel | Topsoil | Brown clay & sand |
| +21.0 | Brown clay w/rock | Brown clay w/gravel | Brown clay/sand/gravel | Brown clay & sand |
| +20.0 | Brown clay w/rock | Brown clay w/gravel | Brown clay/sand/gravel | Brown clay & sand |
| +19.0 | Brown clay w/rock | Brown clay w/gravel | Brown clay/sand/gravel | Brown clay & sand |
| +18.0 | Brown clay w/rock | Brown clay w/gravel | Brown clay/sand/gravel | Brown clay & sand |
| +17.0 | Brown clay w/rock | Brown clay w/gravel | Brown clay/sand/gravel | Brown clay & gravel |
| +16.0 | Brown clay w/rock | Gravel | Brown clay/sand/gravel | Brown clay & gravel |
| +15.0 | Brown clay w/rock | Gravel | Brown gravels | Brown clay & gravel |
| +14.0 | Brown clay w/rock | Gravel | Brown gravels | Brown clay & gravel |
| +13.0 | Brown clay w/rock | Brown clay w/gravel | Brown sandy clay | Brown clay & gravel |
| +12.0 | River gravel | Brown clay w/gravel | Brown sandy clay | Brown clay |
| +11.0 | River gravel to el. +10.5 | Blue sand/clay & gravel | Brown sandy clay | Brown clay |
| +10.0 | Grey clay w/rock | Blue sand/clay & gravel | Brown sandy clay | Brown clay |
| +9.0 | Grey clay w/rock | Blue sand/clay & gravel | Brown sandy clay | Brown clay |
| +8.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| +7.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| +6.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay, sand/water |
| +5.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay |
| +4.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay |
| +3.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay |
| +2.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay |
| +1.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay |
| -1.0 | Grey clay w/rock | Blue clay & gravel | Blue sandy clay | Blue clay |
| -2.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| -3.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| -4.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| -5.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| -6.0 | Grey clay w/rock | Blue clay & gravel | Blue gravels | Blue clay, sand/water |
| -7.0 | Grey clay w/rock | Blue clay & gravel | Brown/yellow sand/clay | Blue clay, sand/water |
| -8.0 | Grey clay w/rock | Blue clay & gravel | Brown/yellow sand/clay | Blue clay, sand/water |
| -9.0 | Grey clay w/rock | Blue clay & gravel | Brown/yellow sand/clay | Blue clay |
| -10.0 | Gravel, little binder | Green clay & gravel | Brown/yellow sand/clay | Blue clay |
| -11.0 | Gravel, little binder | Brown clay w/boulders | Brown gravels | Blue clay |
| -12.0 | Gravel, little binder | Brown clay w/boulders | Brown gravels | Brown clay & boulders |
| -13.0 | Gravel, little binder | Brown clay w/boulders | Brown gravels | Brown clay & boulders |
| Below -13.0 | Hard impervious rock | Stopped drilling | Stopped drilling | Stopped drilling |

| Well Name | Distance From Pumped Well, Feet | Total Depth, Feet | Ground Surface, Elevation MSL | Perforated Interval, Elevation MSL |
|---|---|---|---|---|
| MBCSD Supply Well | 0 | 36 | 25.46 (top of casing) | -12 to +4 |
| Old Well | 10 | Approx. 36 | 24.47 (top of casing) | Approx. -12 to +4 |
| State Park Well | 60 | 32 | 25.55 | Unknown |
| New Monitor Well | 65 | 34.5 | 23.14 | Approx. -12 to +4 |
| P-2 | 62 | 3.75 | 18.65 | 14.9 to 16.9 |
| P-9 | 68 | 4.3 | 18.91 | 14.6 to16.6 |
| P-10 | 100 | 4.5 | 18.36 | 13.8 to 15.8 |
| P-6 | 98 | 3.6 | 15.05 | 11.4 to 13.4 |
| MBCSD Piezometers | 5 – 20 | 8 to 9 | 23.5 to 24.2 | Entire depth |

**Table 2. Construction details for wells at MBCSD Well Site.**

# FIGURES

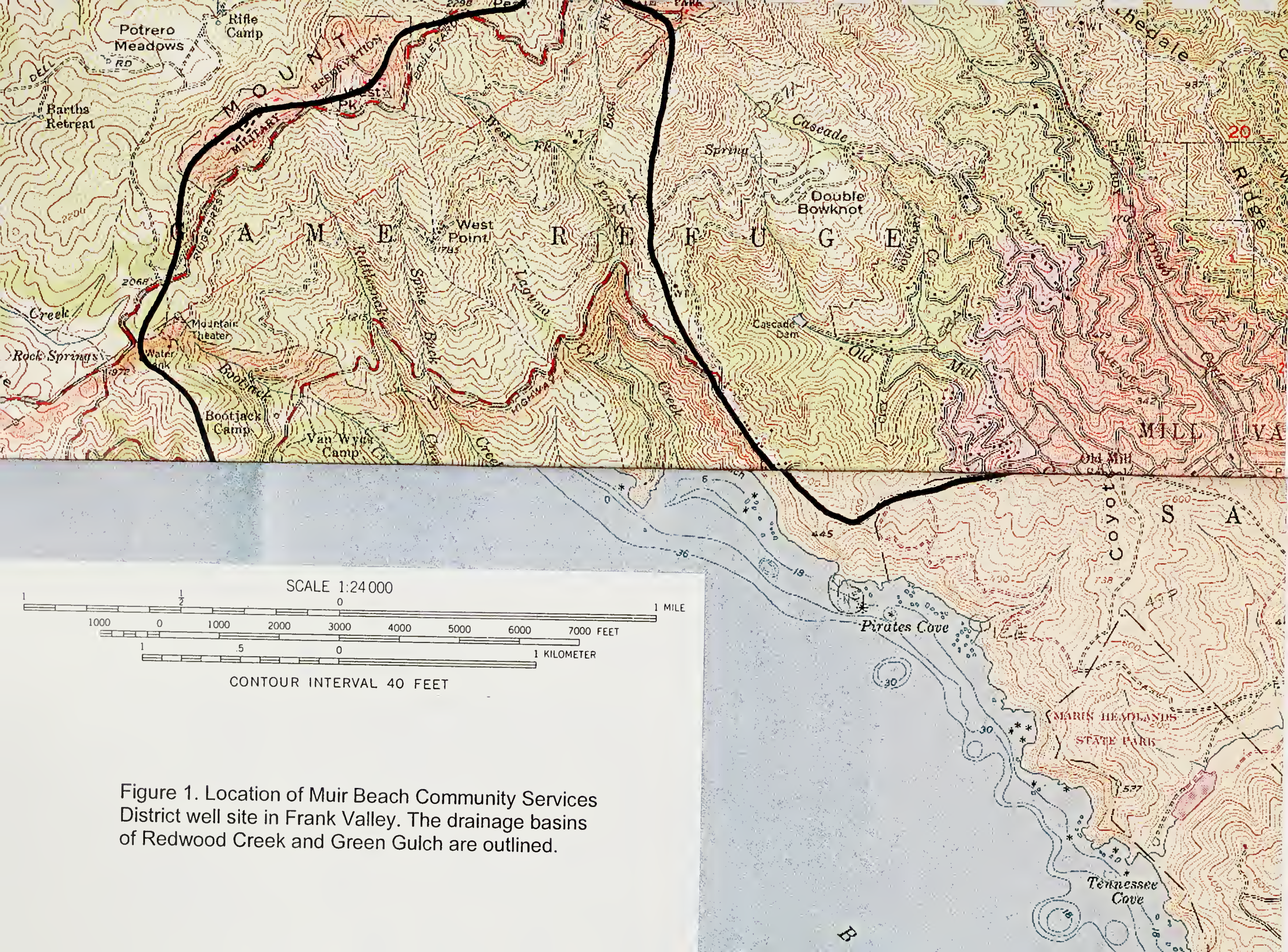



Figure 1. Location of Muir Beach Community Services District well site in Frank Valley. The drainage basins of Redwood Creek and Green Gulch are outlined.


Figure 1. Location of Muir Beach Community Services District well site in Frank Valley. The drainage basins of Redwood Creek and Green Gulch are outlined.

Figure 2. Generalized West-East Cross Section at MBCSD Well Site

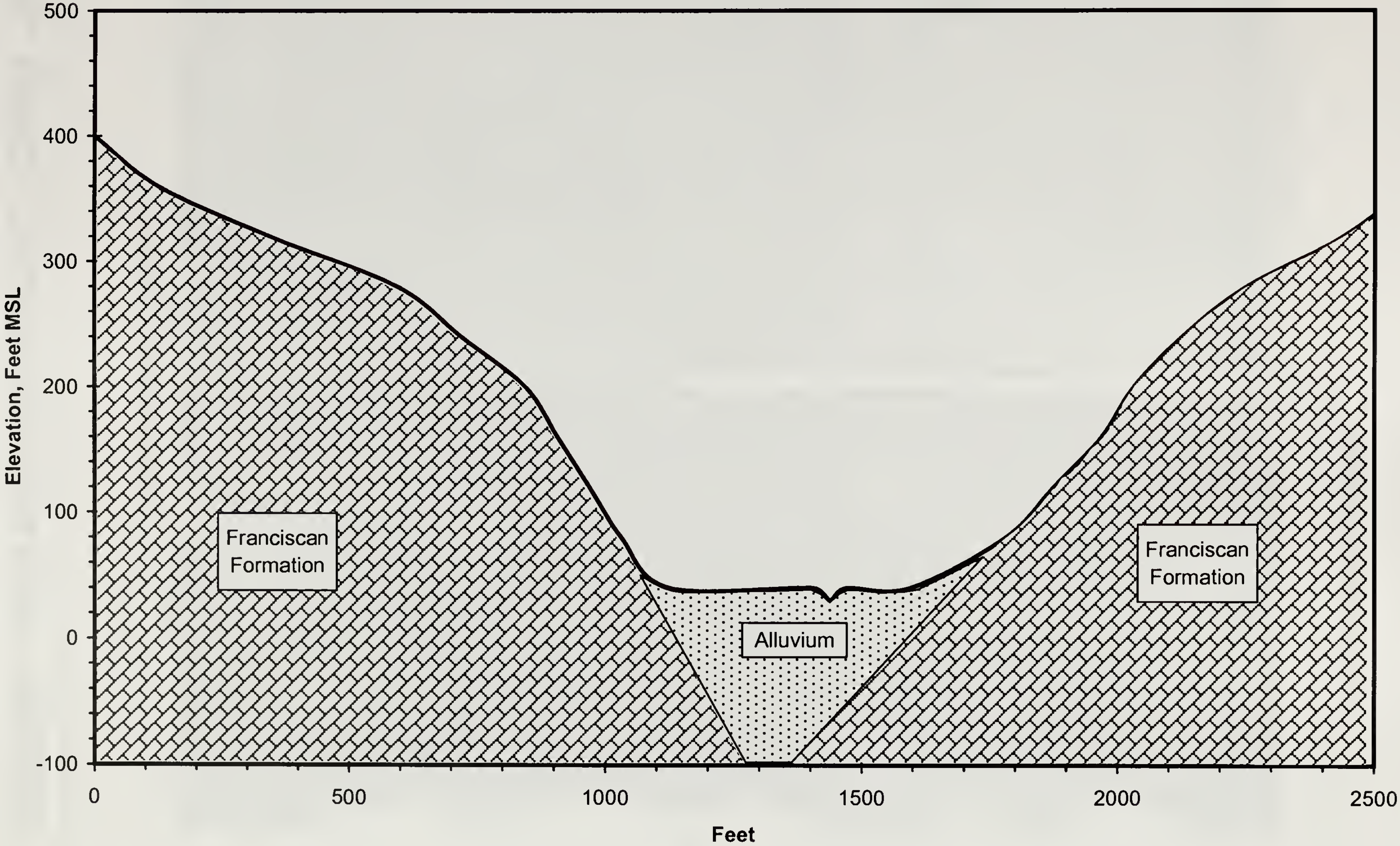
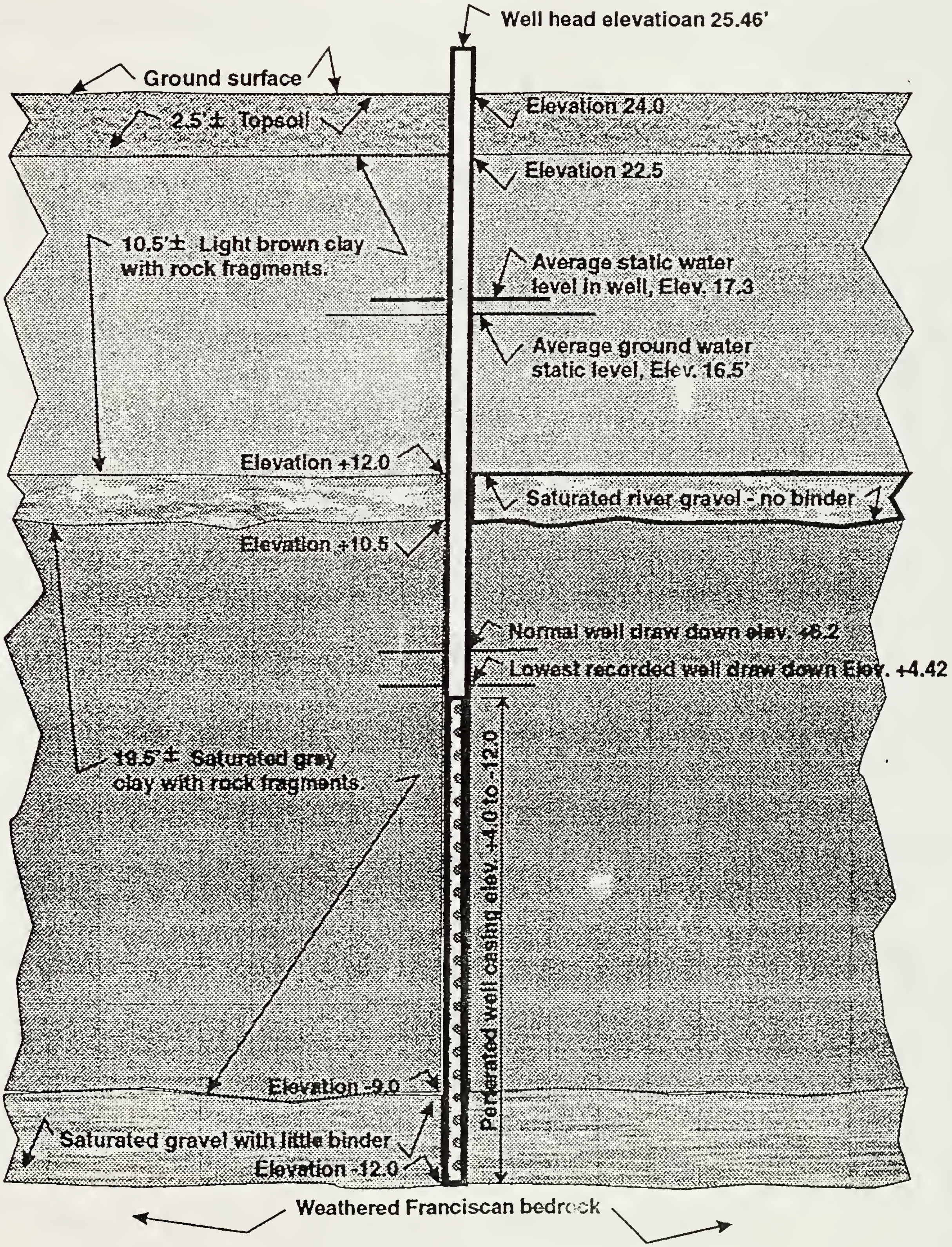


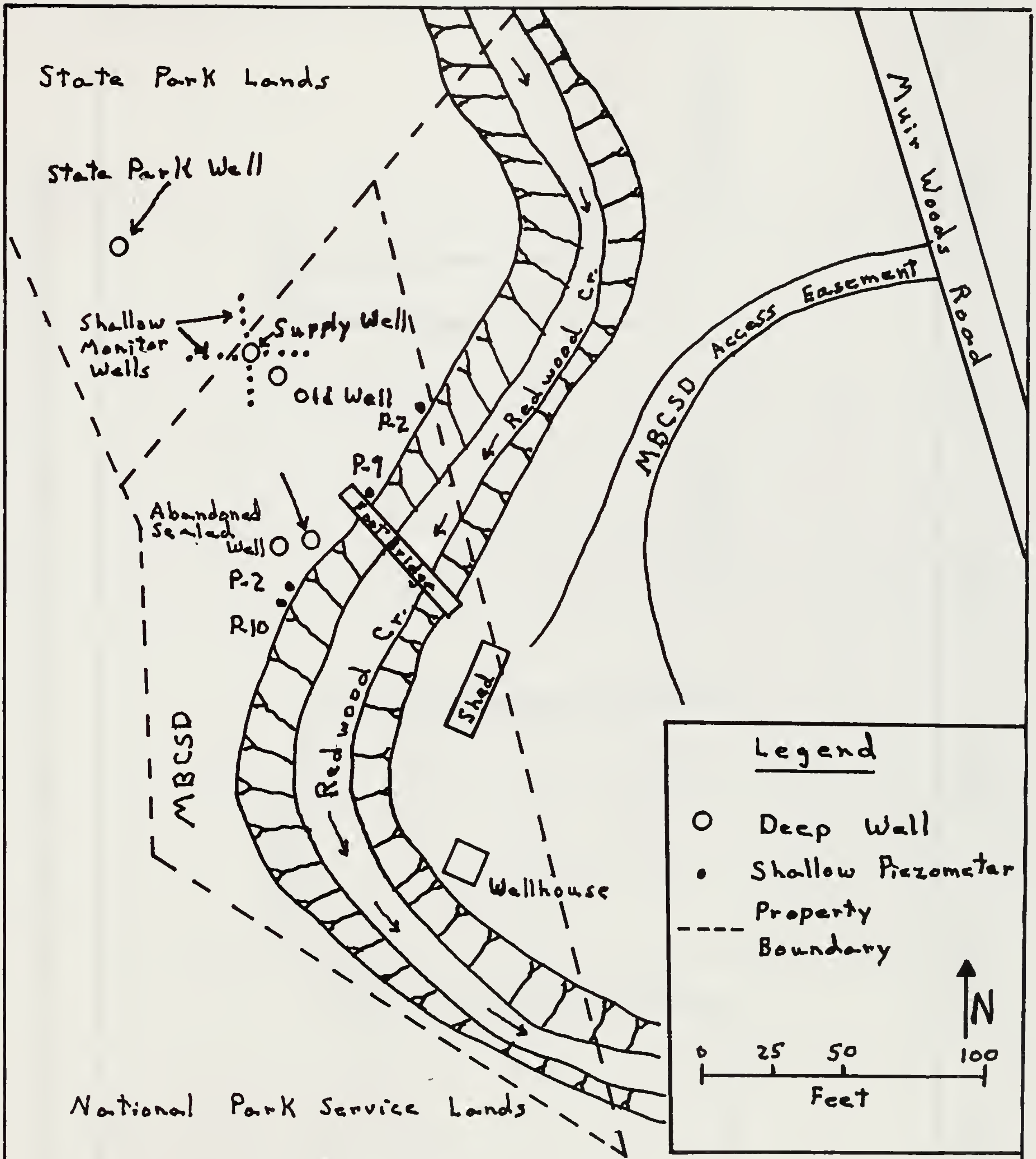
Figure 3




# Muir Beach Community Services District

Sketch of Well Driller's Log for the District's New Primary Well

Scale: 1" = 5'     Well Drilled in June 1996




Muir Beach Community Services District
Sketch Map of Well Site

Figure 4

Figure 5. Pumping and recovery periods for the July 1999 aquifer test MBCSD Well Site

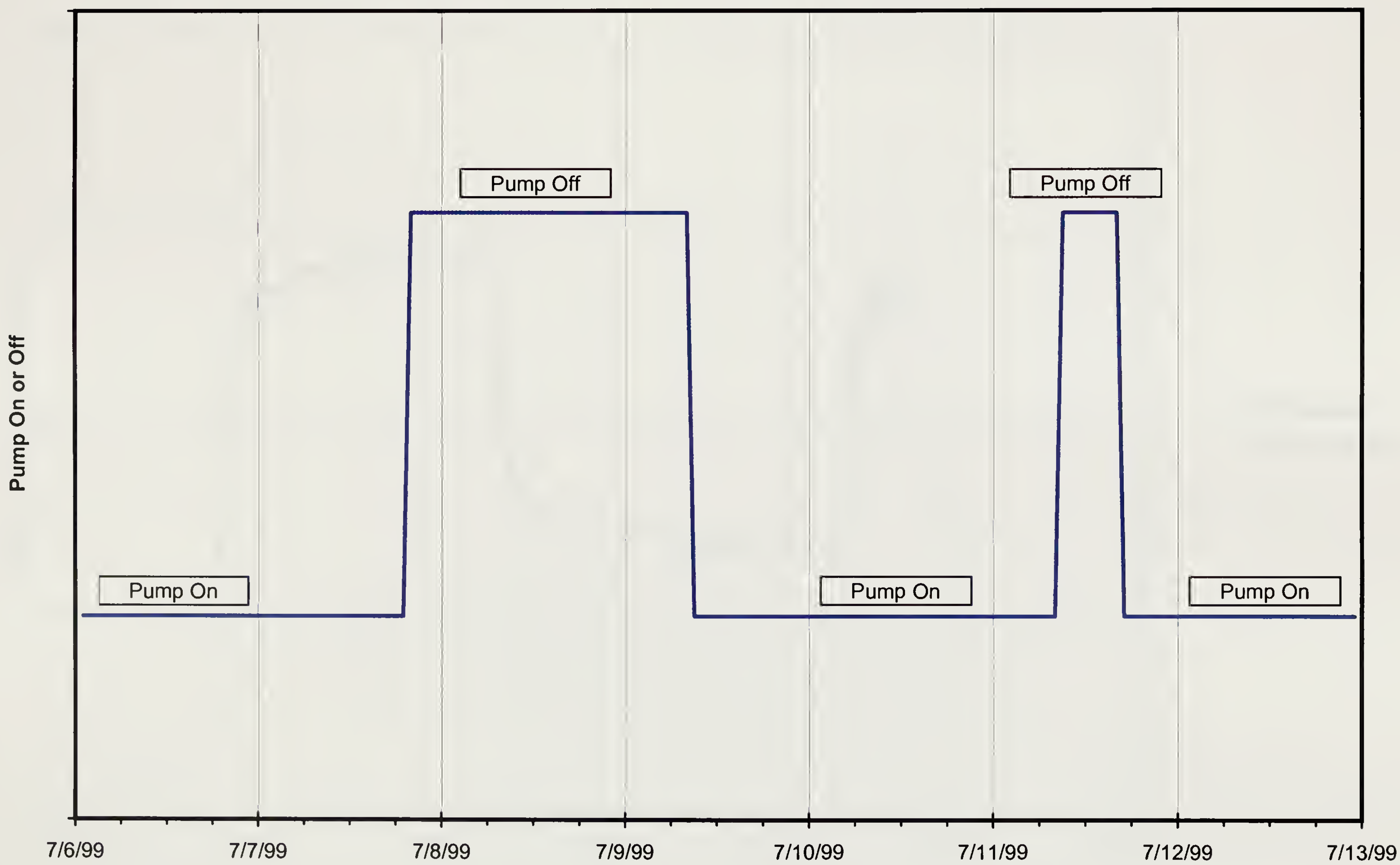
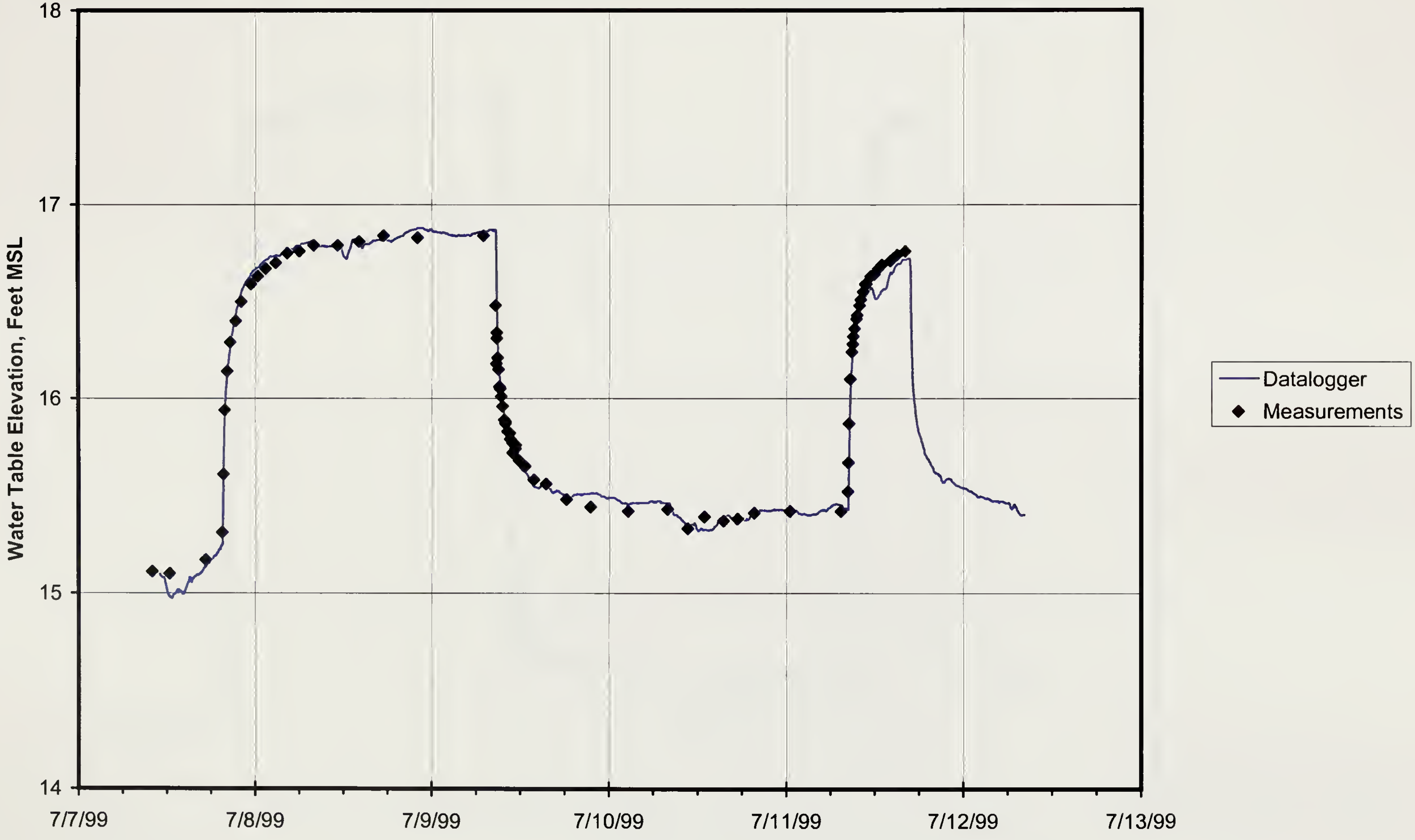


Figure 6. Hydrograph of Old Well



## Figure 7. Hydrograph of State Park Well

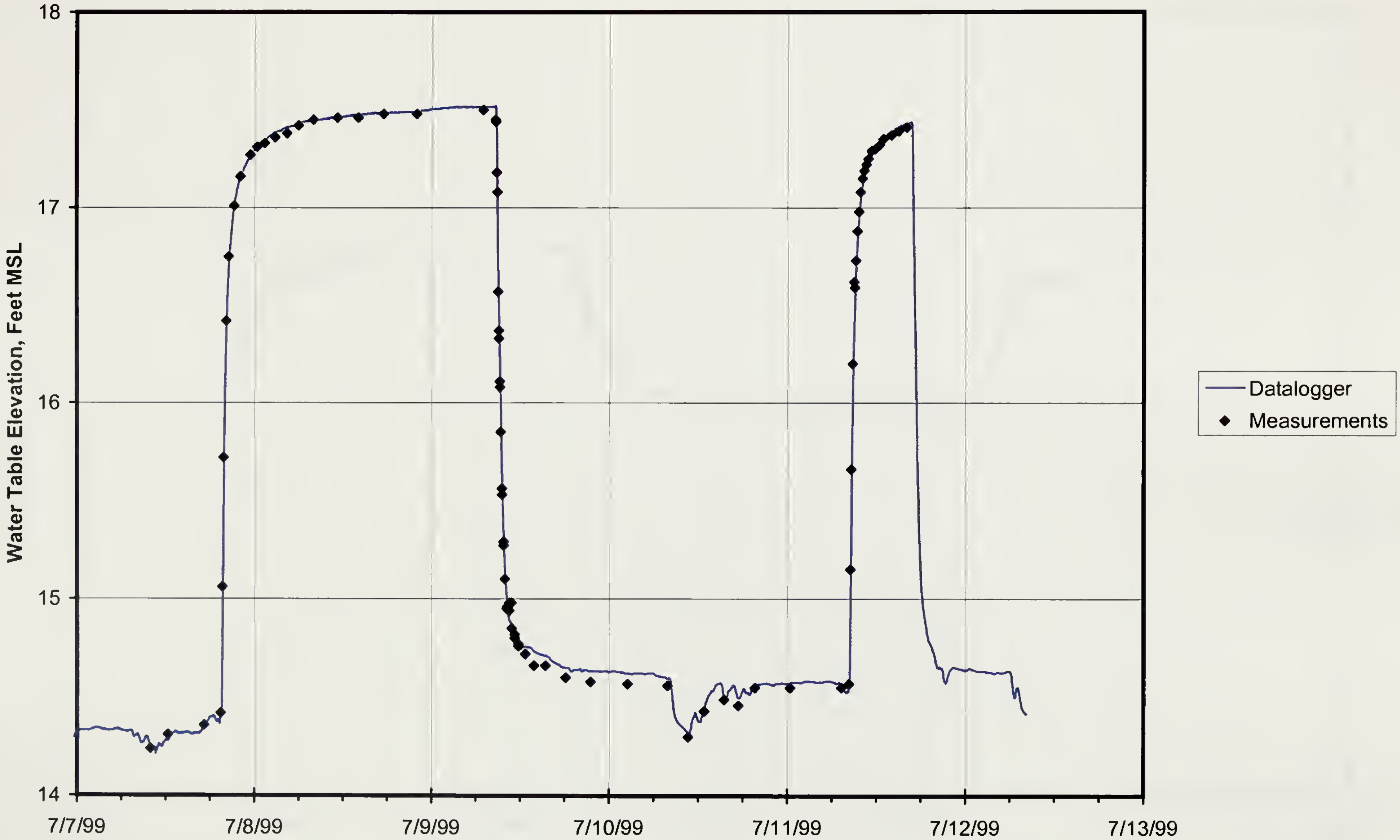


Figure 8.  Hydrograph of New Monitor Well

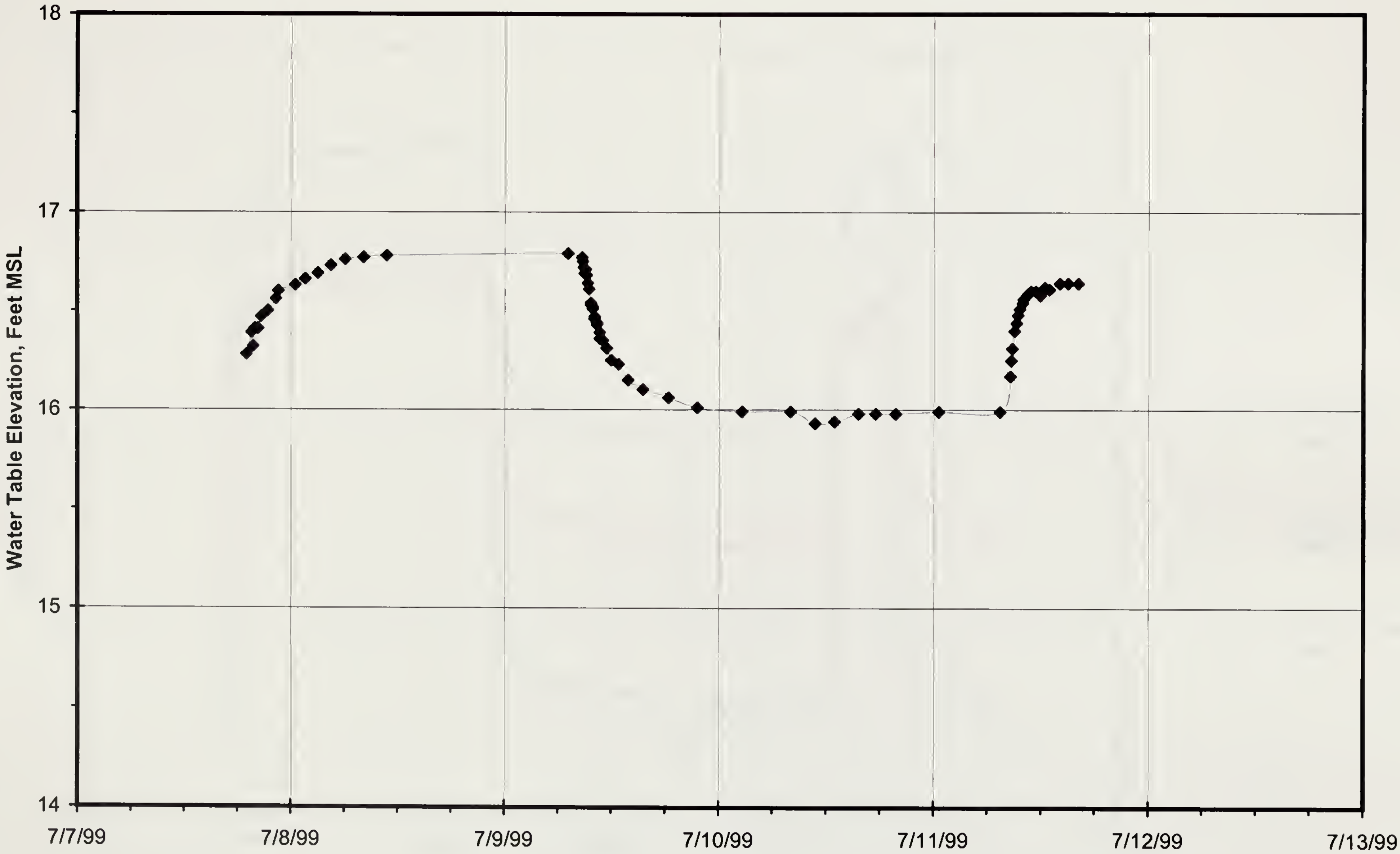


**Figure 9. Hydrographs of Deep Monitor Wells**

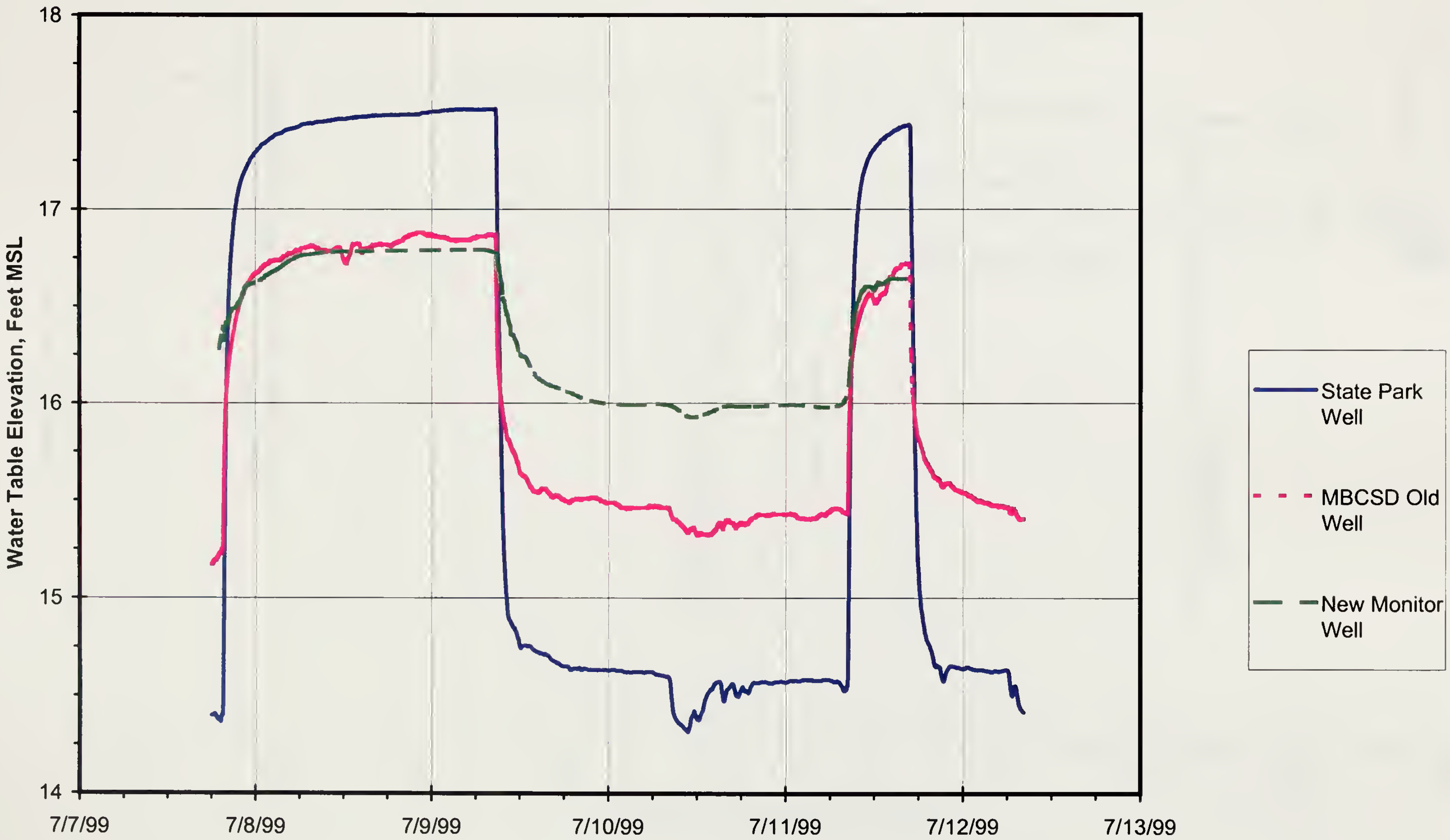
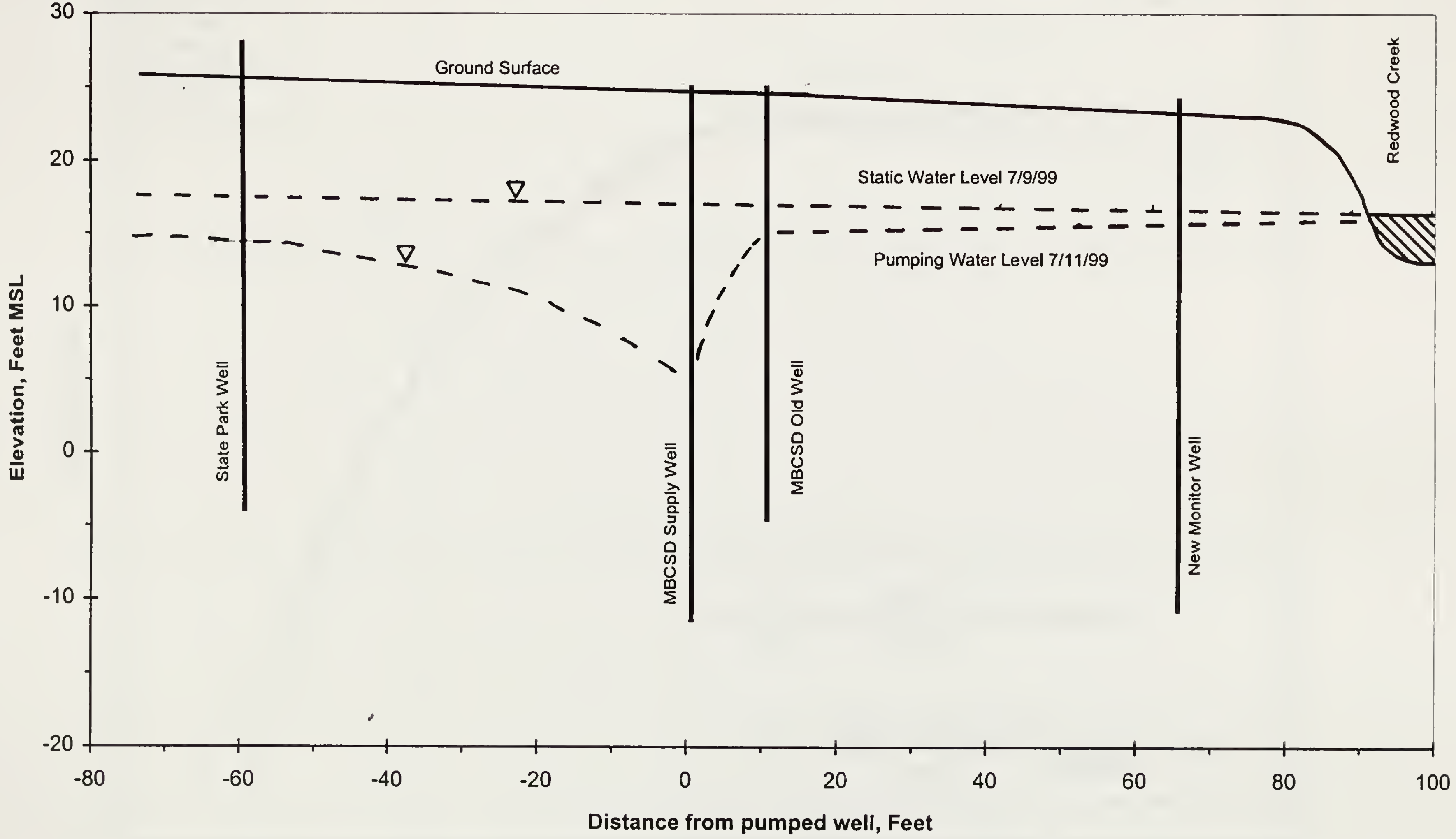
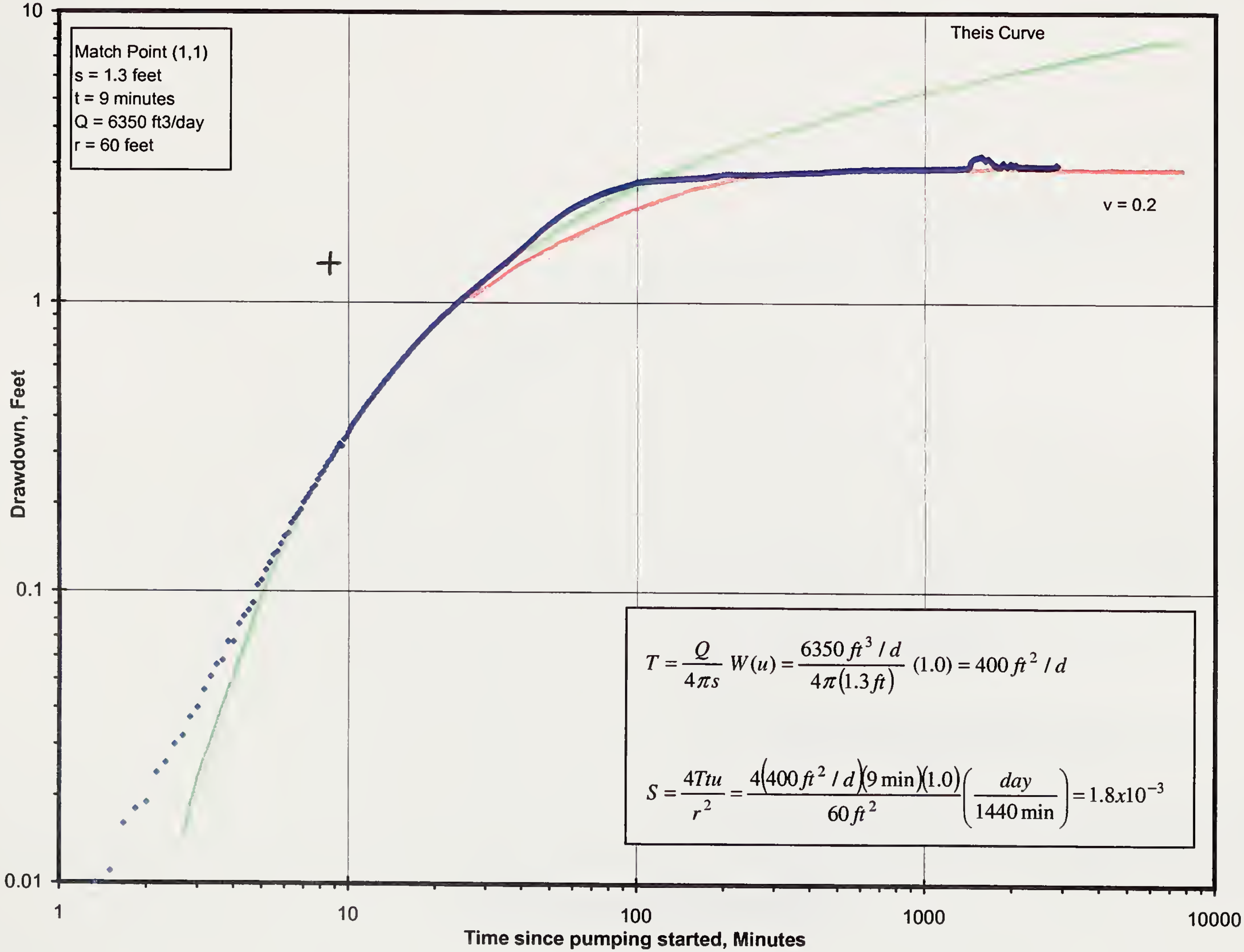


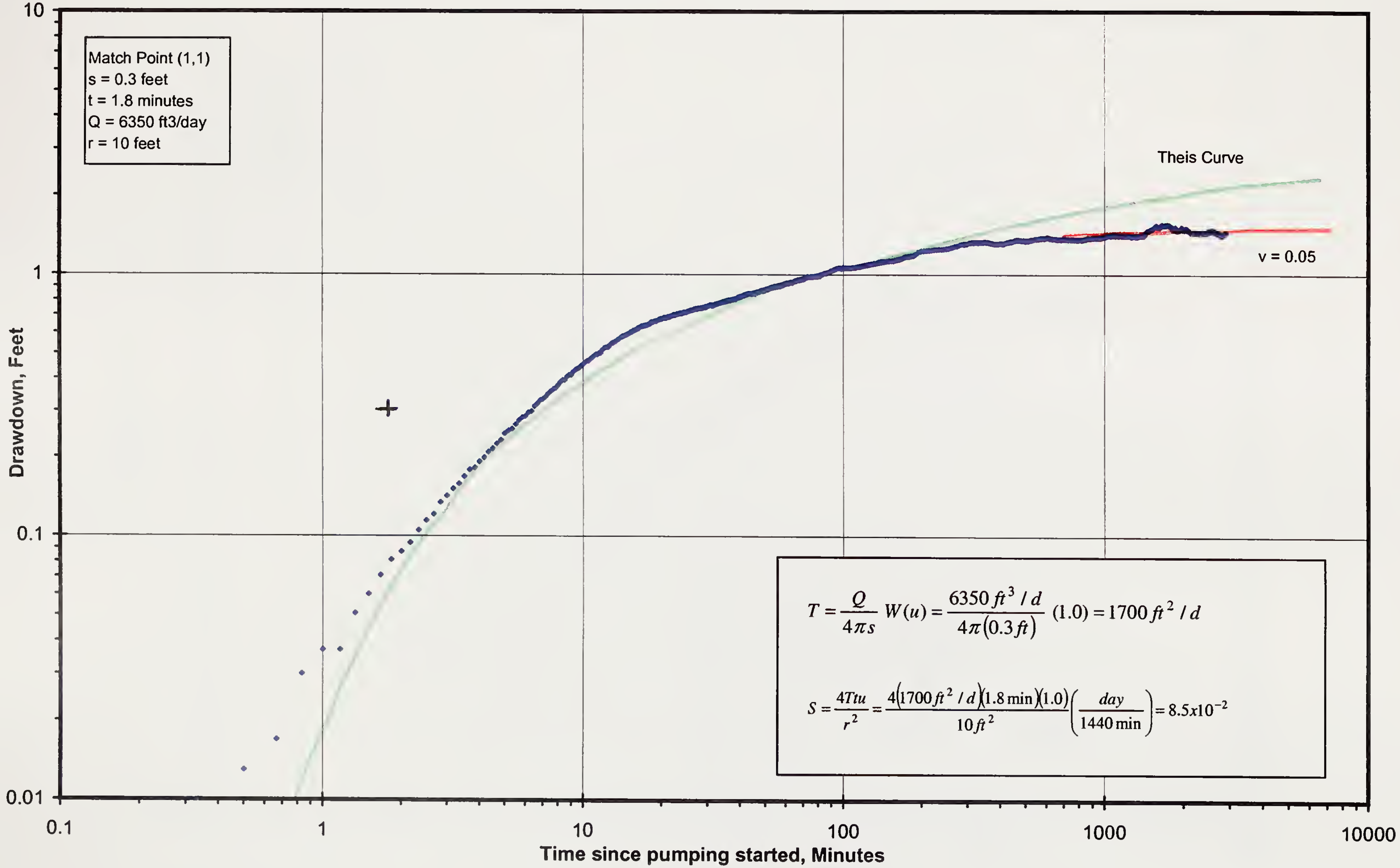
**Figure 10. Hydrologic Cross Section through the MBCSD Well Site, approximately North-South**



## Figure 11. State Park Well
## Pumping Period 7/9/99 to 7/11/99



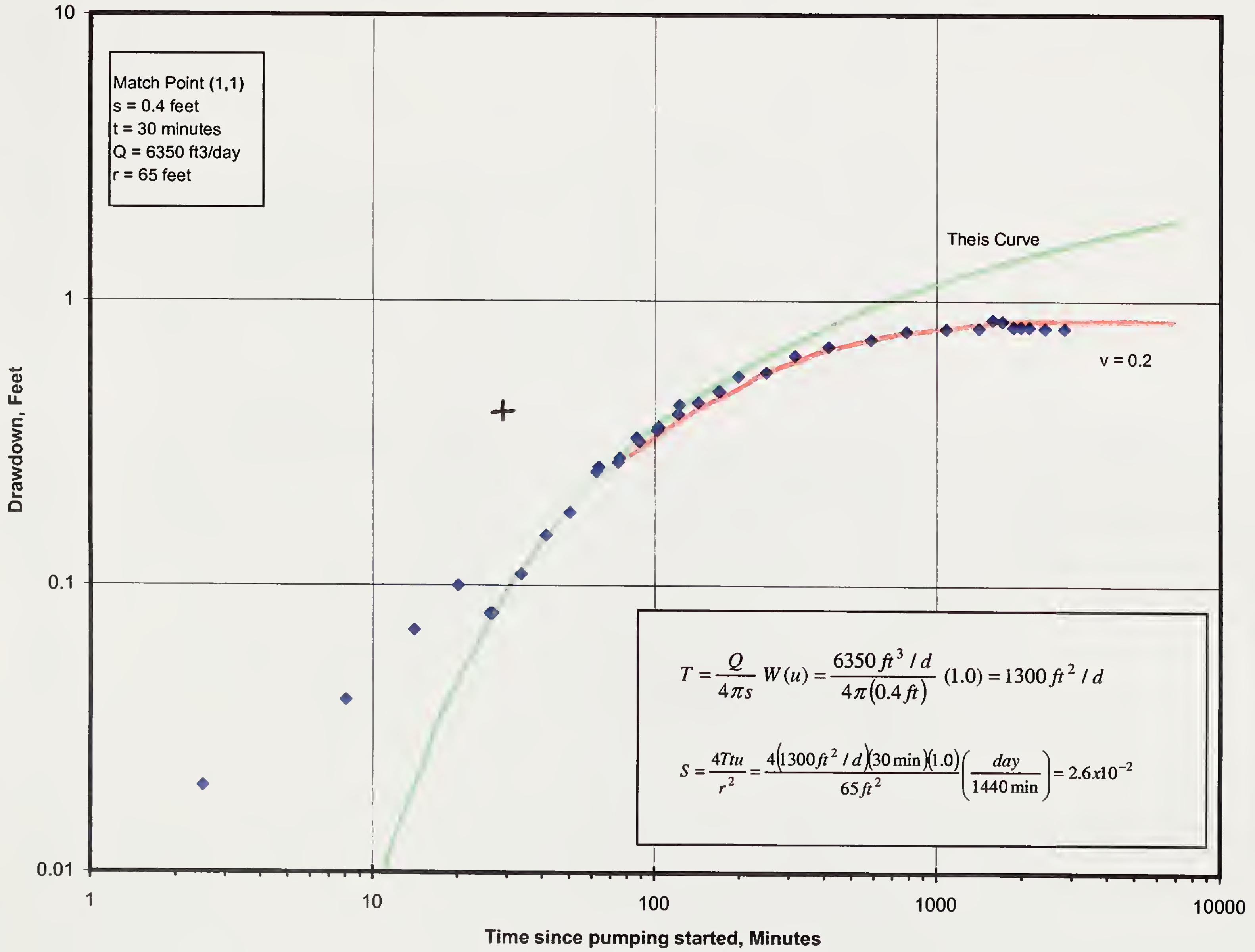
## Figure 12. MBCSD Old Well
## Pumping Period 7/9/99 to 7/11/99

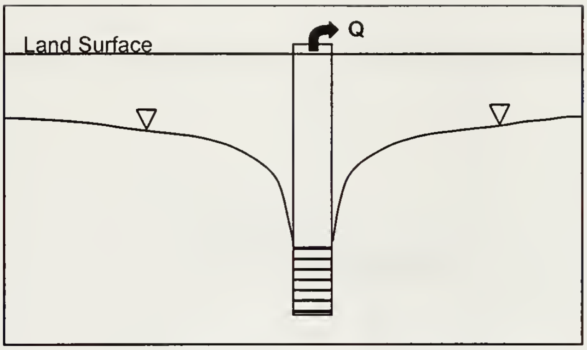



$$T = \frac{Q}{4\pi s} W(u) = \frac{6350\,ft^3/d}{4\pi(0.3\,ft)}(1.0) = 1700\,ft^2/d$$

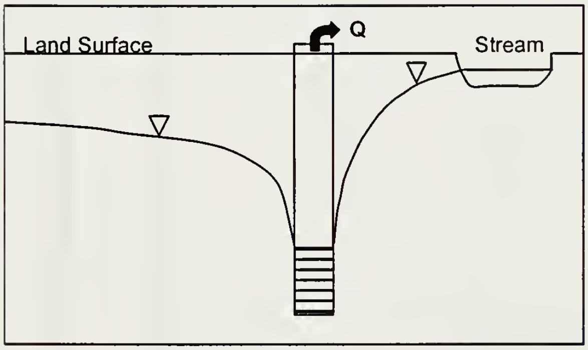
$$S = \frac{4Ttu}{r^2} = \frac{4(1700\,ft^2/d)(1.8\,\mathrm{min})(1.0)}{10\,ft^2}\left(\frac{day}{1440\,\mathrm{min}}\right) = 8.5x10^{-2}$$

**Figure 13. MBCSD New Well**
**Pumping Period 7/9/99 to 7/11/99**

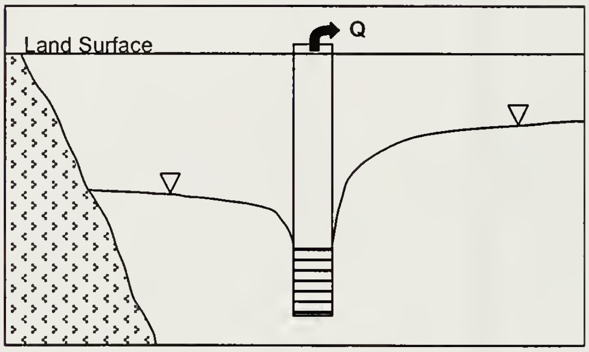




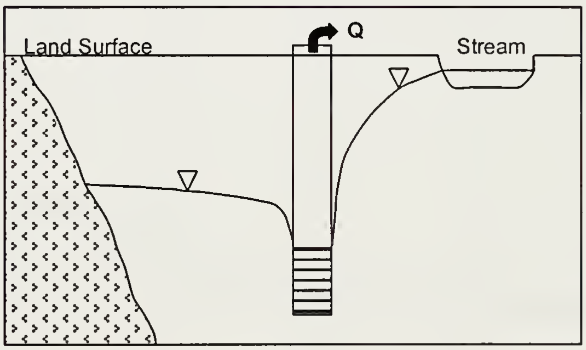

Drawdown in an aquifer with no boundaries




Drawdown in an aquifer bounded by a recharge boundary



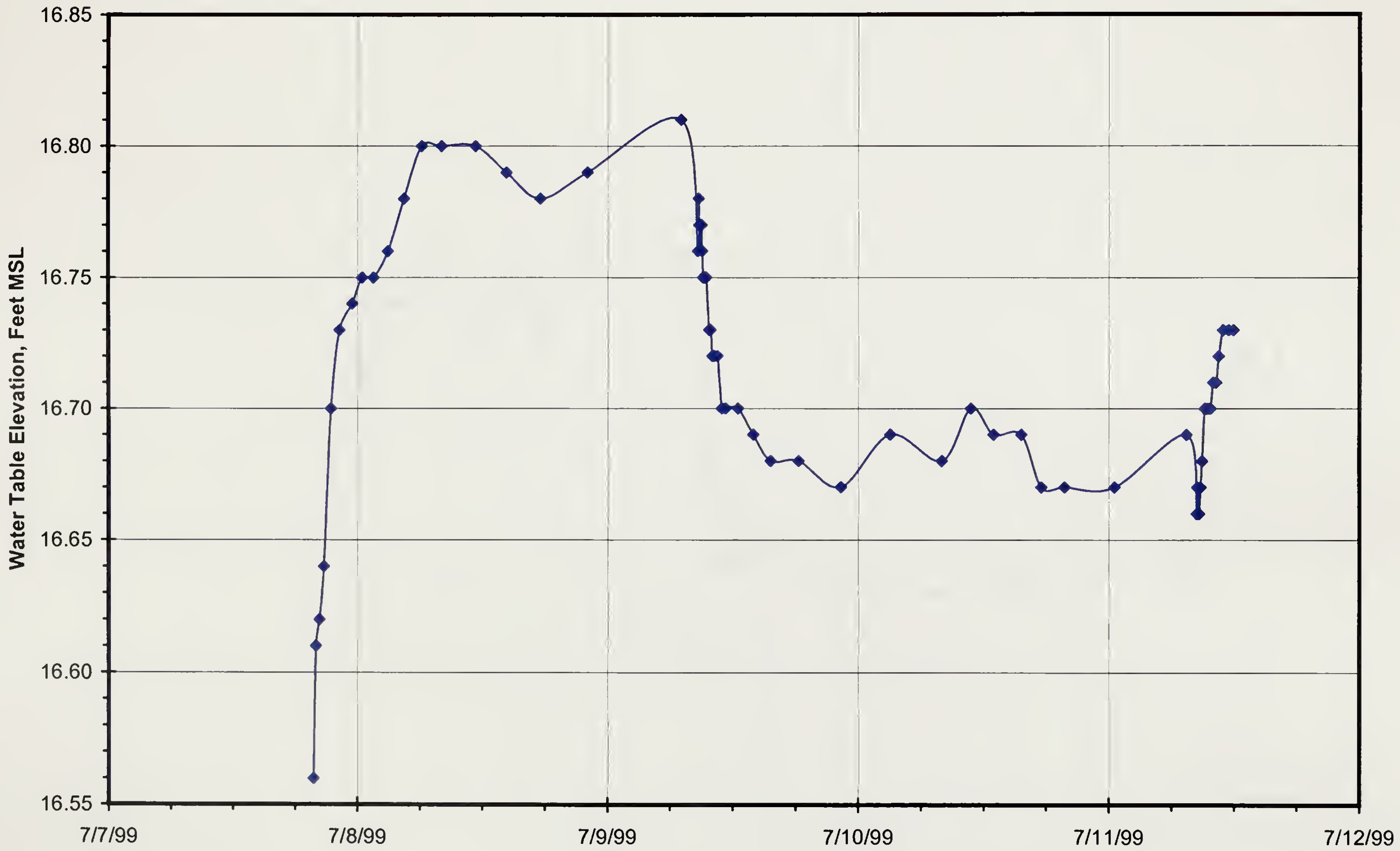

Drawdown in an aquifer bounded by a barrier boundary




Drawdown in an aquifer bounded by
a recharge and barrier boundary

Figure 14. Hypothesized hydrogeologic cross-section through the MBCSD Well Site

Figure 15. Hydrograph of Piezometer P-2



## Figure 16. Hydrograph of Piezometer P-9

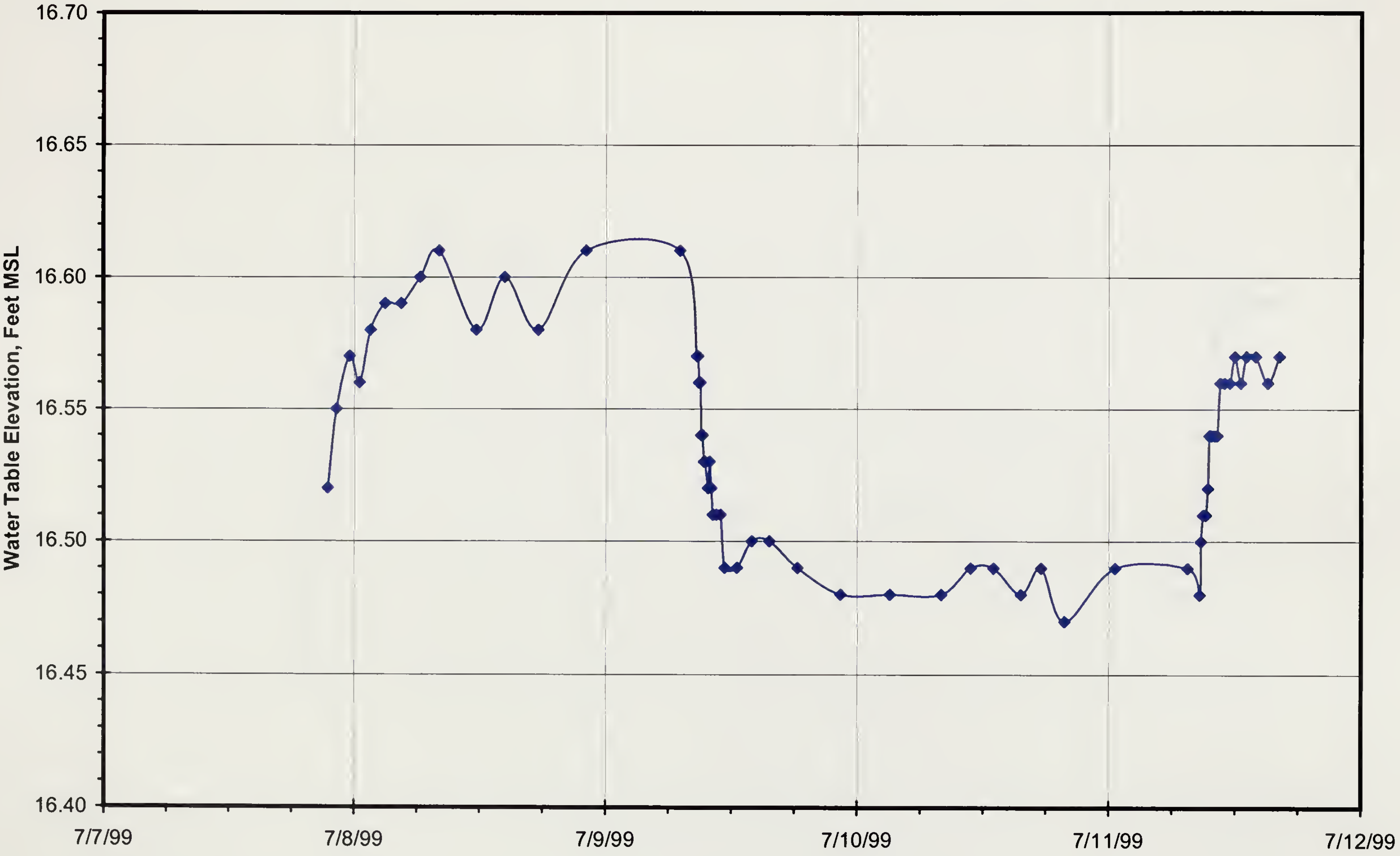


Figure 17. Hydrograph of Piezometer P-6

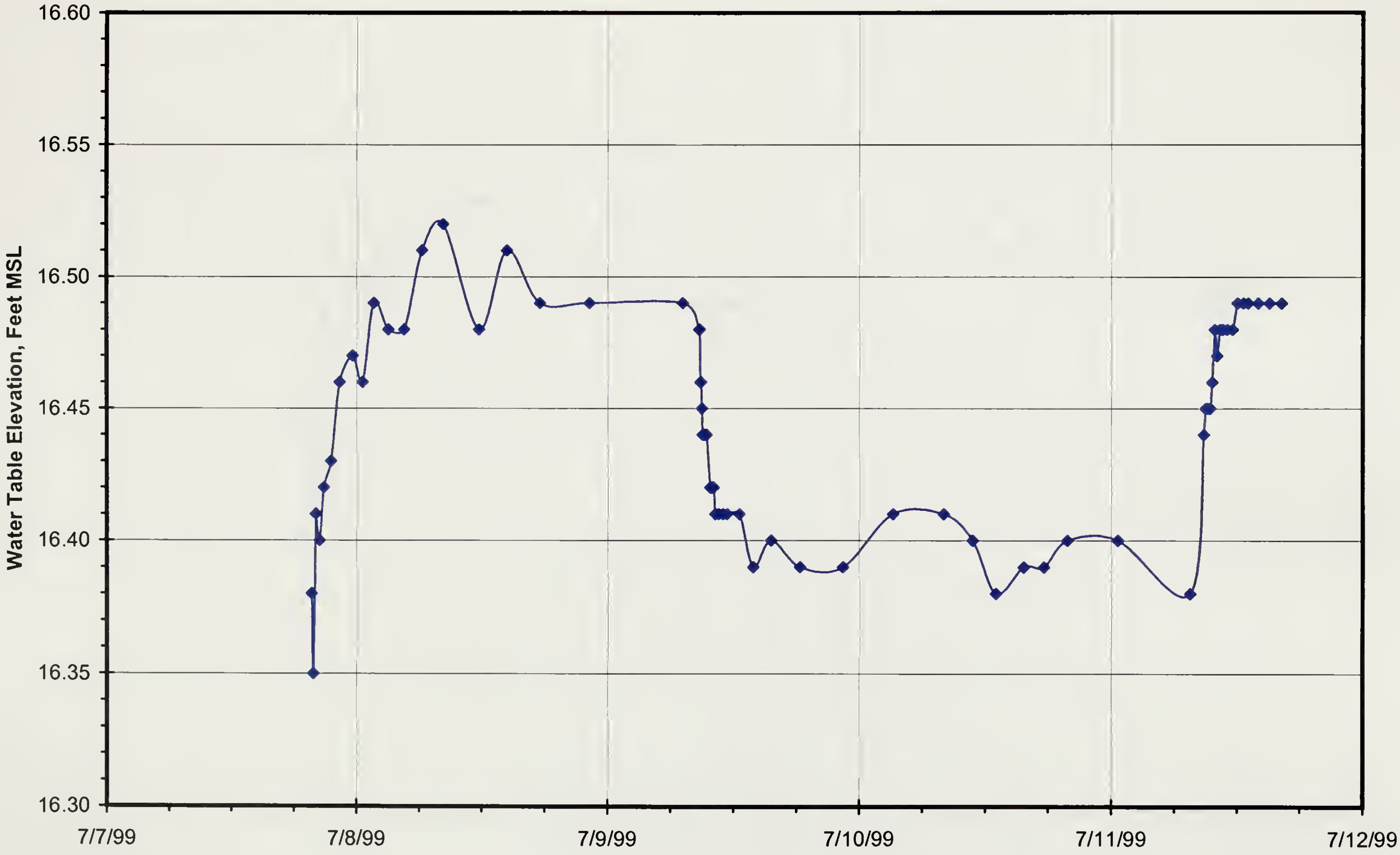


Figure 18. Hydrograph of Piezometer P-10

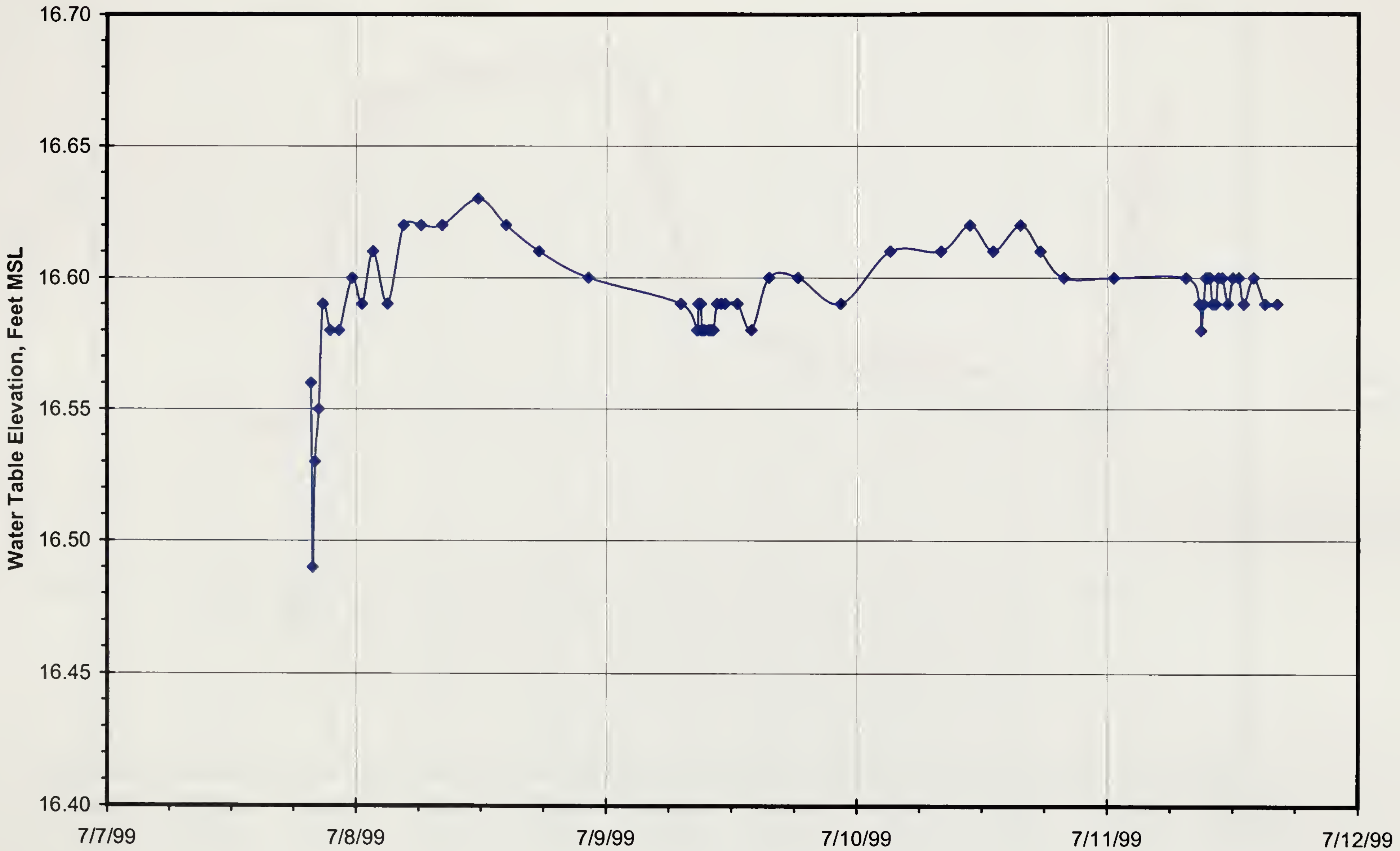


Figure 19. Hydrographs of MBCSD Shallow Monitor Wells, 5-E and 20-E

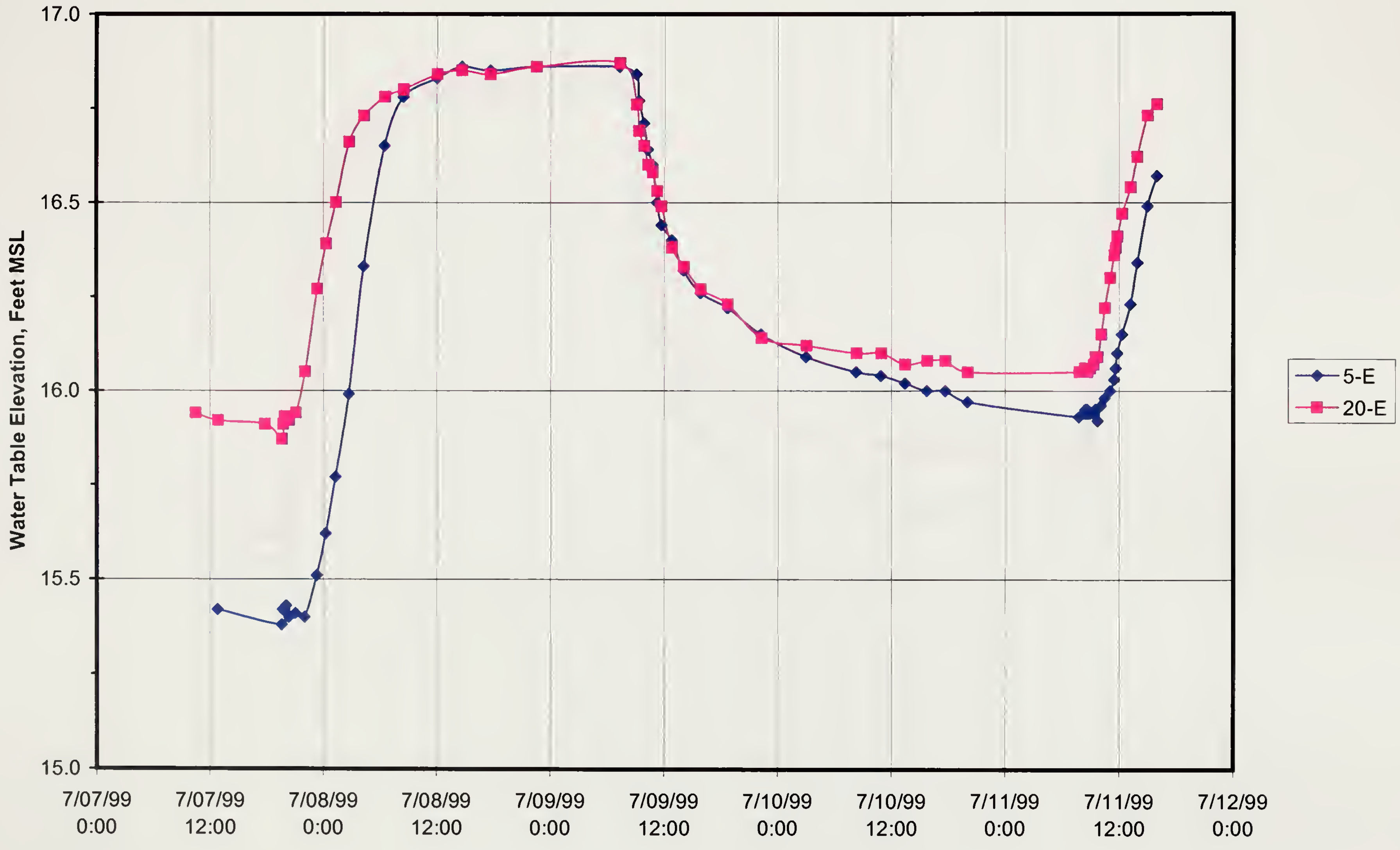


Figure 20. Hydrographs of MBCSD Shallow Monitor Wells, 5-W and 20-W

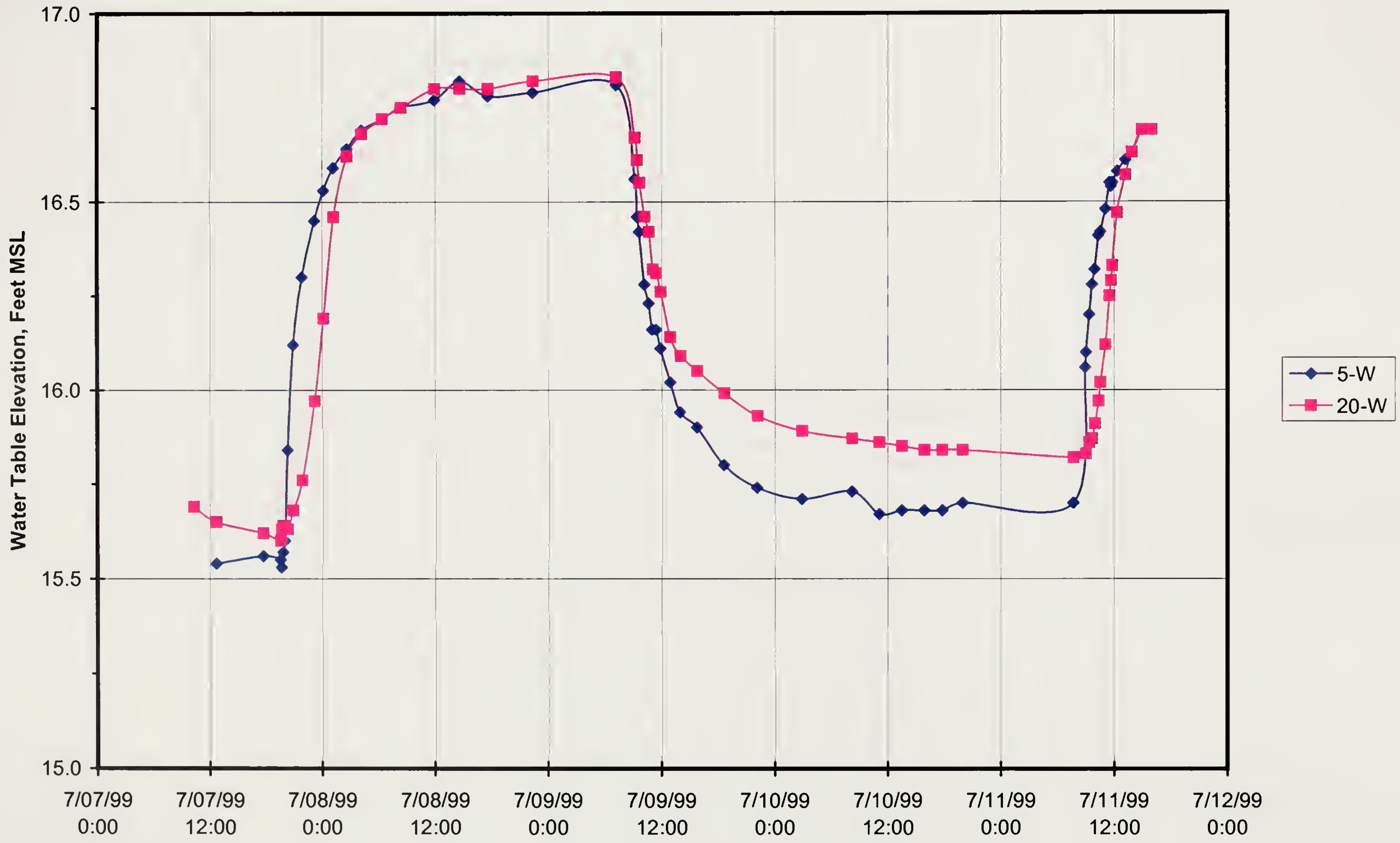


**Figure 21. Hydrographs of MBCSD Shallow Monitor Wells, 5-S and 20-S**

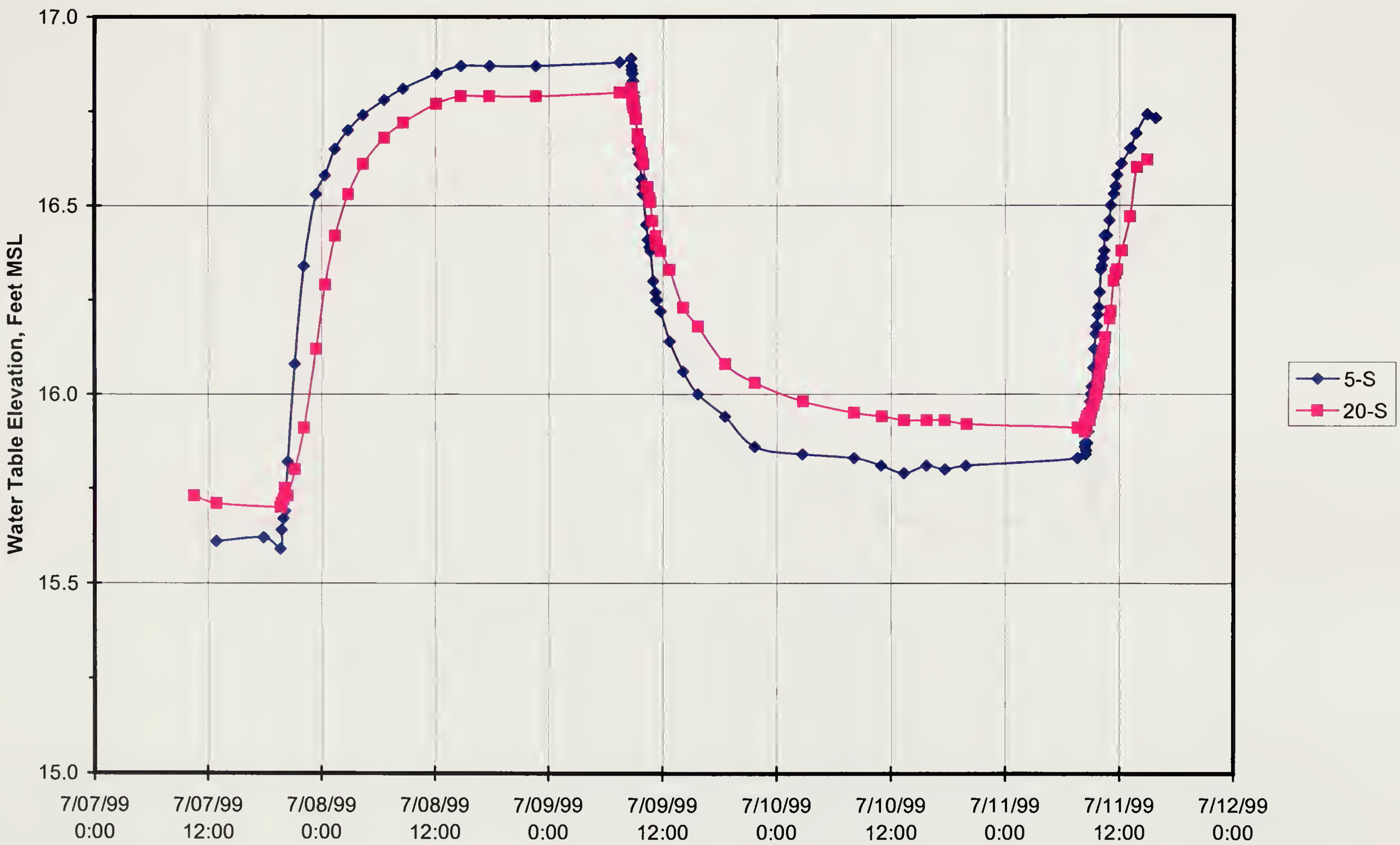


Figure 22. Hydrographs of MBCSD Shallow Monitor Wells, 5-N and 20-N

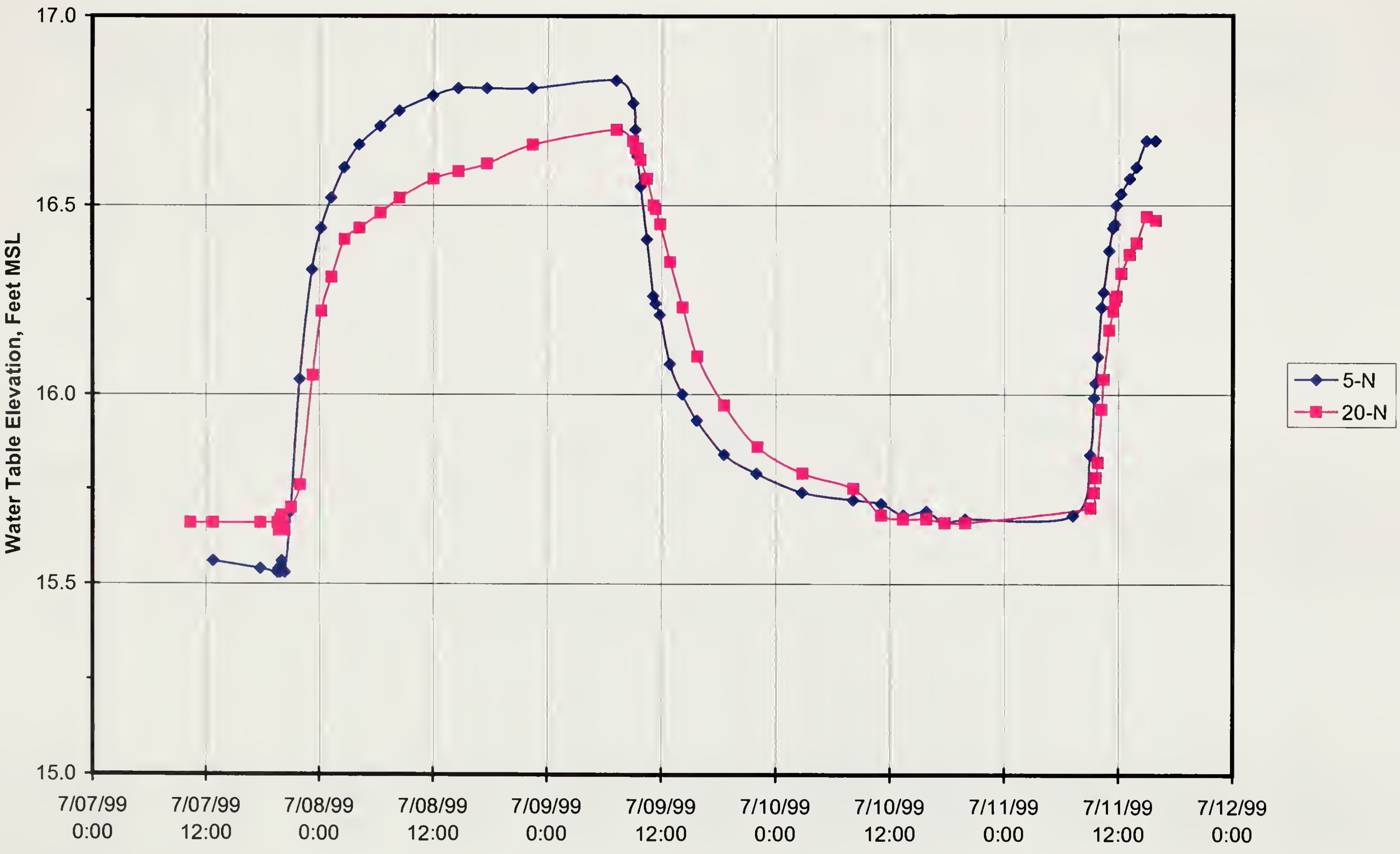
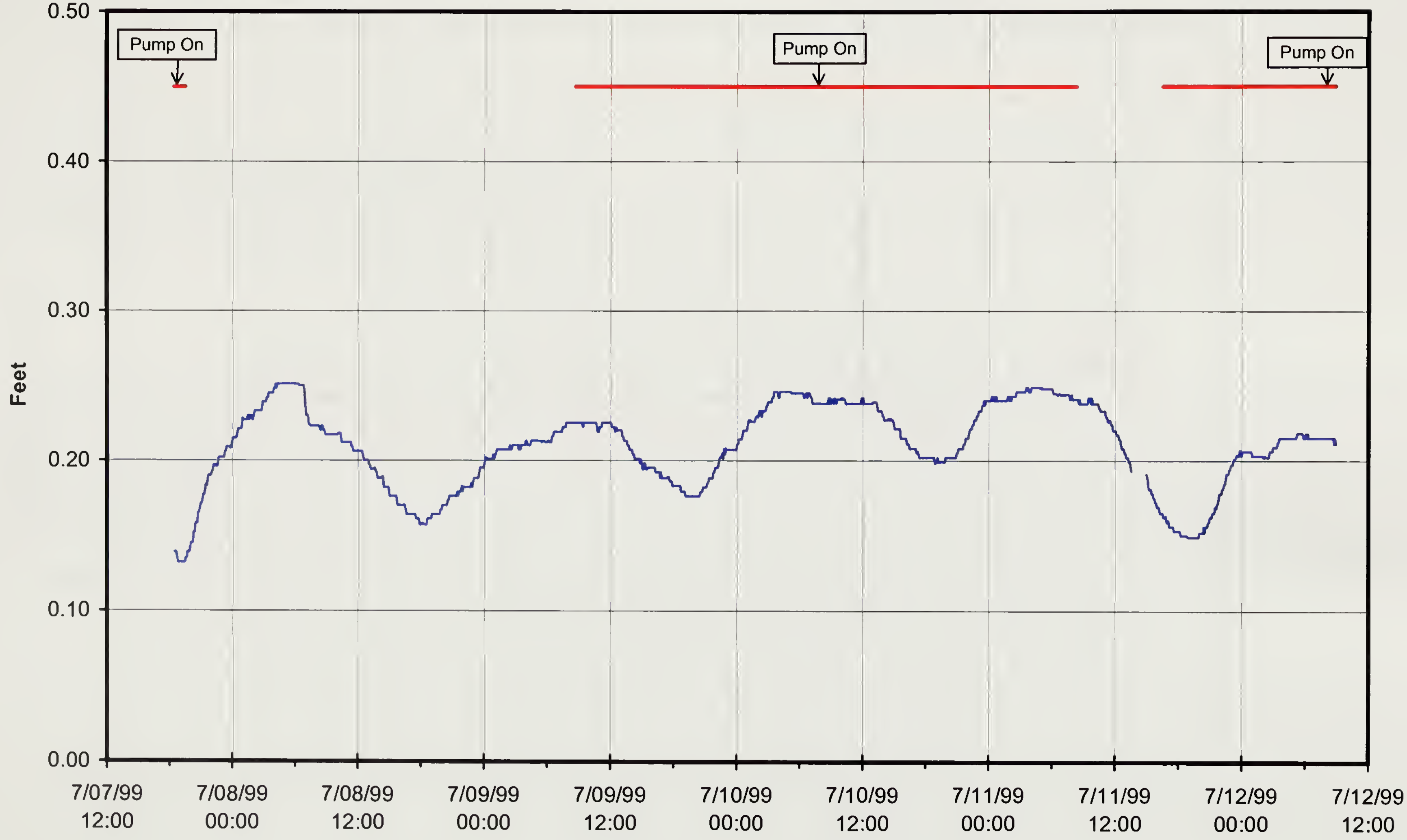


**Figure 23. Hydrograph of Upstream Weir (bottom of v-notch = 0.0)**



## Figure 24. Hydrographs of Staff Gages in Redwood Creek